A PRELIMINARY APPRAISAL

Pollutional Effects of Stormwater and Overflows from Combined Sewer Systems

U.S. DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE
Public Health Service

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NOVEMBER 1964

PUBLIC HEALTH SERVICE PUBLICATION No. 1246
1964

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Summary

Increasing urban development accompanied by progressively more stringent demands on water quality for all uses makes it necessary to examine the various sources of impairment to water. One of the important sources which has lacked attention is the stormwater and overflow from combined sewers. This situation precipitated a preliminary study to define the problem and examine existing and possible solutions along with cost analyses. Four fundamental questions guided the study which sought to learn (a) quantity and quality of the overflows; (b) effects on streams, water uses, and users; (c) adverse effects, and if any, existing or suggested control measures and their effectiveness; and (d) costs necessary for control.

The study revealed that the quantity of overflows is significant in terms of annual average and particularly during times of storms. Some 59 million people live in U.S. communities now served by sewer systems which allow overflows. The annual average overflow is estimated to contain 3 to 5 percent of the untreated sewage and, during storms, as much as 95 percent of untreated sewage. Stormwater quantities are in addition to these amounts. The quality of the overflows reflects a high degree of pollutional load to water courses as measured by the usual standards of biochemical oxygen demand, coliform organisms, solids, etc. Stormwater alone was demonstrated to carry significant amounts of pollutional load, particularly in the early portions of storms when a flushing action occurs.

All types of water use were found to be affected and reports of various types of damage were common, although the job of assigning finite limits in terms of monetary loss is largely undone. Precise information on effects was limited but many reports are available showing that consumptive and recreational uses of water receiving stormwater overflows are prevented because of the frequency of storms and their pollutional contribution.

Effects were found to be uniformly adverse and it was learned that control measures do exist. Complete separation of sanitary and storm sewers and treatment is now considered to be the ultimate solution. This includes separation of all sources of stormwater from the sanitary system. It is established that the separated sanitary wastewater requires treatment, and there is a distinct possibility that stormwater too may require treatment under some circumstances. However, at this time there is insufficient information available to establish specific guidelines for such requirements. Partial separation of sanitary and storm sewers and/or other contributing sources such as roof drainage, areaway drainage, etc., also is used as a compromise. Other methods short of complete separation include holding tanks for stormwater, with or without disinfection, chlorine contact chambers, lagoons and other land depressions, increased storage in sewers and accompanying structures, increased or new treatment capacity, control measures within the sewer system, control of zoning and land use, disinfection alone, and control of infiltration. Only a few of these methods have had actual practice. Others have been considered but remain to be evaluated. Evaluation of the effectiveness of all the methods is lacking or incomplete, primarily because of the scarcity of available sites and because of the complex nature of such evaluation. However, many of the methods appear promising and all should be investigated, in view of the seriousness of the problem.

Completely satisfactory cost estimates were not available but it appears that to provide complete separation throughout the country the order of magnitude would be in the $20–30

billion range. Partial separation would cost a substantial percentage of this figure and all alternate methods for which data were available indicate somewhat lower costs, yet would be in the multibillion dollar range.

In assembling the cost information no consideration was given to the monetary losses which would be borne by communities, individuals, businesses, and/or industrial establishments as the results of extensive physical inconveniences occurring during construction in changeover periods. Such losses could be substantial; for example, retail businesses would find their market limited during the time streets are closed to traffic.

None of the basic questions was answered to the extent that corrective plans of action could be recommended. However, sufficient information was found to confirm that the entire problem is of major importance and growing worse with increasing urbanization and water demands. Therefore, concentrated efforts are necessary to fill in the missing information and to learn what corrective measures can be applied to provide the greatest protection at least cost. Present and long-range effects are involved. Corrective measures will not happen in a short time nor can the investigative job be accomplished quickly. Therefore, there should be prompt initiation of a continuing investigation on a scale which will provide practical results that can be translated into actual practice with minimum delay.

Introduction

Historically the development of our Nation's sewer systems has followed a general pattern. Communities were invariably established on water courses for a variety of reasons, such as transportation, water supply, and a source of power. Diversion of stormwater was the earliest concern of these communities. Open ditches were used first and later closed sewer systems were developed. Discharges were made directly to watercourses, usually at many points. In general they followed the most accessible gravity route. These developments were prior to the installation of public water supplies.

As public water became available and the water carriage principle for removing waste from the household was adopted, it was necessary to collect and dispose of the wastewater. To accomplish this the existing storm sewers were used to carry the sewage in addition to stormwater. Thus, during storms when the sewers became overloaded, flooding of combined sewage and stormwater occurred. These developments created the original problem of combined sewer overflow, although there was little early recognition of its significance as a serious source of pollution.

Importantly at the time, there was no sewage treatment. The objective was to collect and discharge all possible contents of sewers into the nearest watercourses. However, as the population density increased and the effects of wastewater discharges became known, the need for treatment became apparent to those concerned with the protection of the Nation's waters and the public health.

As the public in many communities became increasingly aware of the need for treatment of sanitary wastewater, the many short sewers discharging untreated domestic waste to various points in the stream had to be intercepted and the collection system modified to deliver the waste at a single point—the treatment plant. If the system were designed to collect and deliver all sanitary waste and stormwater to the treatment plant, sewers and treatment plant of adequate size would be far beyond practical and economic limits. Therefore, a compromise was necessary—combining the stormwater with the sanitary wastewater, allowing the excess during periods of unusually high flow to overflow directly to the stream.

Because the overflow is a mixture of sanitary wastewater and stormwater, this compromise retains the problem of sending untreated waste directly to the stream. The ameliorating factor has been that during the periods of overflow the stormwater from the system and already in the stream usually provides additional dilution to the sanitary waste. However, with increasing urbanization and its accompanying demands for high quality water, the needs for elimination of all sources of water pollution are steadily intensifying.

The generally accepted engineering practice in this country has been to design these combined sewers to handle during storms two to three times the dry weather flow. Bypassing the excess directly to the watercourse is accomplished by any of several schemes. Even though stormwater provides dilution of sanitary waste, a disturbing factor which must be considered is the flushing of accumulated organic material in the sewers with the early flooding of stormwater. This phenomenon is responsible for substantial organic loading of streams during storms.

Although the general nature of the stormwater separation problem has been recognized for many years, technical and economic information are lacking on how best to solve it. Studies on record have been limited and scattered and only a few communities now sewered actually have provided or plan to install facilities for the separation or treatment of mingled storm and sewage flows which exceed treatment plant capacities. A primary reason for this limited number of communities now with separate sanitary and storm sewers has been the high cost of the separation plus the very significant possible need for separate treatment of stormwater.

In recent years, a recognition of the need to separate sanitary wastewater and stormwater is seen in the present trend to design and construct new sewer systems for complete separation. Nevertheless, a substantial number of existing sewered communities has some type of combined system. The latest Public Health Service inventory of municipal sewerage facilities (1), shows more than 1,300 U.S. communities with combined sewer systems serving 25.8 million people. Another 630 communities of 33.1 million population have both combined and separate systems. Table I breaks down by population size group and by States the U.S. communities with combined systems only and those with both combined and separate systems. Since there now are some 118 million people served by some type sewer, the 59 million people affected by the combined systems represent 50 percent of the total sewered population. Most of the remaining 70 million people are expected to be served by sewers within the next several years. This group can benefit substantially from studies of sewer separation problems resulting in improved and/or alternative solutions.

In new suburban communities it is now common practice for the developer to install separate systems in the initial construction of homes. Frequently the developer's responsibility ends with the termination of the storm sewer at the property line. It then remains for the county, city, or other responsible jurisdiction to develop the stormwater collection system further. This is a real step forward but is no final solution in the frequent instances when the stormwater discharges directly to a small watercourse and thus continues to add organic matter and hydraulic loading far beyond the stream's natural limits.

Congress recognized the problem of combined sewers in its recent consideration of S.649, introduced by the Honorable Edmund S. Muskie (D. Me.). In providing testimony on this bill the current status of combined vs.

Table I.—U.S. Municipalities With Combined Sewer Systems

	Combined systems only		Combined and separate systems	
	No. of communities	Population served	No. of communities	Population served
Population size group				
Under 500	57	17,864	17	4,330
500–1,000	168	118,571	35	24,060
1,000–5,000	592	1,160,495	224	455,586
5,000–10,000	175	908,516	130	768,117
10,000–25,000	171	1,893,010	97	1,241,042
25,000–50,000	73	1,909,950	64	1,893,677
50,000–100,000	48	2,258,960	27	1,783,605
Over 100,000	29	17,581,939	36	26,958,890
States				
Alabama	0	0	0	0
Alaska	0	0	13	58,360
Arizona	1	20,000	0	0
Arkansas	2	64,300	0	0
California	12	2,057,910	0	0
Colorado	1	107,000	0	0
Connecticut	16	490,919	8	421,900
Delaware	1	2,700	6	238,520
District of Columbia	0	0	1	1,323,470
Florida	2	21,500	0	0
Georgia	3	914,515	2	268,920
Hawaii	0	0	0	0
Idaho	10	48,905	2	9,200
Illinois	155	4,693,140	29	1,835,280
Indiana	202	2,445,065	3	36,040
Iowa	18	184,760	10	402,350
Kansas	1	107,000	3	176,400
Kentucky	27	658,620	5	41,445
Louisiana	0	0	0	0
Maine	39	198,650	31	210,608
Maryland	8	16,800	3	2,500
Massachusetts	37	954,205	14	2,115,180
Michigan	95	4,252,685	67	1,292,275
Minnesota	29	1,185,710	1	19,690
Mississippi	0	0	1	18,600
Missouri	6	44,945	20	1,407,760
Montana	4	19,600	7	65,940
Nebraska	13	26,790	5	245,150
Nevada	4	80,600	0	0
New Hampshire	28	91,350	27	144,600
New Jersey	15	366,375	3	1,311,185
New Mexico	0	0	0	0
New York	53	519,525	49	10,192,945
North Carolina	1	1,020	0	0
North Dakota	48	196,855	0	0
Ohio	123	1,735,680	56	3,110,420
Oklahoma	0	0	0	0
Oregon	37	610,280	6	43,100
Pennsylvania	158	707,915	113	6,144,115
Rhode Island	1	0	2	386,470
South Carolina	0	0	0	0
South Dakota	20	15,925	7	19,170
Tennessee	5	195,125	1	142,100
Texas	1	55,000	1	58,100
Utah	0	0	0	0
Vermont	13	10,060	46	176,317
Virginia	1	180,000	4	181,050
Washington	43	826,805	13	302,030
West Virginia	47	425,471	19	87,970
Wisconsin	33	1,315,600	52	640,147
Wyoming	0	0	0	0
U.S. Totals	1,313	25,849,305	630	33,129,307

separate sewers was summarized by Health, Education, and Welfare Secretary Celebrezze in part as follows:

"No real knowledge exists today as to what a national separation program might cost, although estimates have been made in billions of dollars. Even the extent of pollution caused by unseparated sewers is not known, although preliminary studies suggest it is very great . . . Before instituting a federal program for assistance in the separation of combined sewers, the ultimate cost and duration of which are speculative, we need to obtain realistic estimates of the costs of a separation program . . . Once reasonably accurate information as to total cost of a national separation program is obtained and alternative methods have been fully explored, we will be able to make informed decisions among the alternatives and present recommendations to Congress based thereon. Consequently, I am unable to support this provision of the bill at this time, because I do not think we have adequate information."

In hearings before the Natural Resources and Power Subcommittee of the House Committee on Government Operations, May 22, 1963, the separation of sanitary wastewater and stormwater was discussed in detail. Several significant facts were brought out in testimony by David H. Howells, Chief of the Construction Grants Branch, Division of Water Supply and Pollution Control of the Public Health Service, as follows:

1. Conditions during the 19th century, when many of the Nation's older cities developed their sewer systems, were such that 20th century requirements for a higher degree of water resources management were not predicted.

2. Most treatment plants handling wastes from combined systems were developed under a procedure by which 3 to 5 percent of the annual sewage flow is discharged directly to the stream, untreated, through combined sewage overflows. The stormwater also washes large amounts of deposited sludge out of the sewers, resulting in considerable pollutional load to the watercourses. For example, data from Buffalo, N.Y., some years ago indicate that about one-third of the city's annual production of sewage solids overflowed without treatment although only 2 to 3 percent of the sewage volume actually overflowed.

3. Even though a few studies have been made on combined wastewater composition and the influence of combined overflows on streams, the information is not applicable to other cities unless the precipitation pattern, character of the runoff area, capacity and design of sewer system, and conditions in the receiving waters are comparable.

It is known that the overflows from combined sewer systems and the discharge of stormwater from storm sewers create real pollution problems. The extent of these problems is not known in sufficient detail to outline a comprehensive and sound plan or plans for solution. Investigation of the problem has been scattered and generally lacking in depth with results of limited usefulness. However, the work already done shows that there are several possibilities for alternate or modified solutions to supplement or improve existing or planned programs.

It is the purpose of this report to examine and assess in a preliminary way existing data on stormwater and combined sewer overflows in regard to characteristics and pollutional effects, and to investigate existing and possible corrective measures for dealing with the problem.

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Plan of Investigation

Time limitations and the preliminary nature of this study made it necessary to accumulate and examine data which were readily available. Sources of data included:

1. More than 50 engineering reports and completed questionnaires dealing with sewer systems and/or sewage treatment. In general, these were preliminary reports or planning studies and, except for a few written specifically about stormwater, they discussed separation only as a part of an overall community problem. These reports discussed communities with populations ranging from a few thousand to more than eight million. The appendix lists the reports studied.

2. Several special reports prepared by municipalities or agencies which covered in detail studies and recommendations regarding stormwater separation. Some of these dealt specifically with stormwater separation, and others as a part of an overall problem, but all had in common the inclusion of water quality data. The appendix lists these reports also.

3. On-site interviews with representatives of Cleveland, Ohio.; New York, N.Y.; Philadelphia, Pa.; Washington, D.C.; Portland, Oreg.; Salem, Oreg.; Eugene, Oreg.; Tacoma, Wash.; Seattle, Wash.; Spokane, Wash.; Vancouver, Wash.; Kansas City, Mo.; Kansas City, Kans.; Mission Township Sewer District, Kans.; Minneapolis-St. Paul (Minn.) Sanitary District; State water pollution control agency representatives of Oregon, Washington, Kansas, and Missouri; and several of the Public Health Service river basin projects, regional offices, and comprehensive study stations.

4. Correspondence with a number of cities in various areas throughout the United States.

In evaluating the problem of combined sewers the following fundamental questions controlled the study:

1. What is the quantity and quality of the wastewater?

2. What effects do the discharged wastes have on the stream and on water uses and users?

3. If the effects are adverse, what control measures exist or can be recommended and how effective will the control be?

4. How much will the control cost?

To organize the study it was necessary to search for and tabulate existing information with certain specific categories in mind. Wide variations in local conditions create special problems of placing data in a form to obtain a common frame of reference. To aid in accumulating the necessary information, a questionnaire was developed. Because of its complexity and comprehensive nature it was not readily adaptable for completion by mail. Therefore, in most instances where used it was completed from published information or from interviews with individuals involved in specific municipal combined systems or separation projects.

Categorically, the primary specifics sought were:

1. Fundamental statistics such as population; sewered population served by separate, combined, or both; availability of engineering reports; and treatment plant characteristics and performance data.

2. Detailed characteristics of combined and stormwater sewer overflows.

3. Characteristics and frequencies of overflow in combined system.

4. Water uses affected by overflow from combined sewers.

5. Damage attributed to combined sewer overflows.

6. Land use.

7. Basic data and hydraulics for interceptors.

8. Stream quality.

9. Rainfall and effects on systems.

10. Regulating devices used in combined systems.

11. Infiltration to collection systems.

12. Detailed data on remedial action including plans for or existence of separate sewers, treatment, storage, and other methods of handling stormwater and/or combined overflows.

13. Cost data for projects in (12) above.

Fundamental Data From Engineering Reports and Questionnaires

Table II (pp. 6–9) summarizes the fundamental statistical information as obtained from the engineering reports examined and the questionnaires completed for several municipalities where engineering reports were not available. Since the engineering reports were prepared for a variety of reasons, such as wastewater treatment needs, relief of flooding conditions, long-range plans for metropolitan collection and treatment programs, etc., there is no consistency in format. Further, the dates of the reports varied from 1946 to 1963. Most reports were preliminary; therefore, performance data were not available. In these instances the "1962 Inventory of Municipal Waste Facilities" (1) was used to supplement the information, particularly for quantity of wastewater and treatment performance. These variable factors point up that a considerable degree of judgment is necessary in evaluating the information from the various sources.

Despite the obvious deficiencies in source information, these reports brought out some significant facts. They represent 55 communities in 25 States and the District of Columbia, with a total population of 20 million and total sewered population of 23 million. Of the 55 communities, 9 were indicated to have separate sewer systems, 10 have combined systems, and 36 have combinations of combined and separate systems. Of those with combined or combined and separate systems, 9 are in varying stages of separation programs.

In comparison with the information in table I, this study indicates a strong sampling of the large cities. For instance, the 10 largest study cities represent more than 19 million sewered population. In table II, 55 communities representing 23 million sewered population are included. In comparison, there are in the United States a total of 59 million people in 1,943 communities with combined or semicombined sewer systems (table I). Throughout the United States the ratio of the number of communities served by both combined and separate systems to those served by combined systems only is 0.48, whereas in this sampling the same ratio is 3.6. However, in developing the preliminary study the larger communities were examined because of the availability of information from these sources.

In the 55 communities studied, 9 had no treatment facilities, 25 had primary plants, and 30 had secondary plants, either trickling filter or activated sludge. Within these totals are several cities having multiple treatment facilities.

The inability to obtain complete data for total wastewater flow, treatment plant design, and treatment performance prevented valid summations. The available data are nevertheless included for their individual use.

Where applicable, the results of personal interviews as mentioned in the Plan of Investigation are incorporated into table II. Other information resulting from these discussions is included later.

Most of the data in the special reports referred to in the Plan of Investigation deal with the separation studies and are discussed later.

Characteristics of Combined and Stormwater Flows

Wastewater and stormwater reaching receiving streams without treatment originate from combined sewer overflows directly to streams, stormwater sewer discharges directly to streams, and/or bypasses of wastewater by treatment plants and pumping stations, usually occurring during storms. It is useful to examine the findings of others who have studied this problem in specific cases.

Review by Others

In a classical study of overflows from combined sewers McKee (2) found in the Boston, Mass., area that stormwater runoff equal to the

Table II.—Summary of Sewer and Treatment Information as Obtained From Engineering Reports and

City	Engineer report		Engineer making report	Population (1960 census)	Estimated total sewered population	Line No.
		Date				
Amsterdam, N.Y.	Yes	1947	William S. Lozier Co., Rochester, N.Y.	28,772	[a] 35,525	1
Ashland, Ky.	Yes	1957	J. Stephen Watkins & Howard K. Bell, Lexington, Ky.	31,283	[a] 31,500	2
Atlanta, Ga.	No			[b] 61,000	[c] 67,000	3
Boston, Mass.	Yes	1962–1963	Charles A. McGuire & Associates, Boston, Mass.	[d] 697,197	[e] 400,000	4
Chattanooga, Tenn.	Yes	1948 & 1952	L. A. Schmidt, Jr. & Polk, Powell & Henderson, Chattanooga, Tenn.	130,009	130,000	5
Chicago, Ill.	Yes	1962	Black & Veatch, Kansas City, Mo.	3,550,404	4,768,590	6
Clarksville, Tenn.	Yes	1961	J. Stephen Watkins, Lexington, Ky.	22,021	13,200	7
Cleveland, Ohio	Yes	1963	Stanley Engr. Co., Muscatine, Iowa	876,050	1,272,372	8
Clinton, Iowa	Yes	1958	Consoer, Townsend & Associates, Chicago, Ill.	33,589	[e] 30,000	9
Des Moines, Iowa	Yes	1963	Veenstra & Kimm, Des Moines, Iowa	208,982	208,000	10
Elmhurst, Ill.	Yes	1959	Baxter & Woodman, Crystal Lake, Ill.	36,991	36,880	11
Eugene, Oreg.	Yes	1961	Cornell, Howland, Hayes & Merryfield, Corvallis, Oreg.	50,977	45,000	12
Findlay, Ohio	Yes	1961	Jones, Henry & Williams, Toledo, Ohio	30,344	30,345	13
Hannibal, Mo.	Yes	1959	Stanley Engr. Co., Muscatine, Iowa	20,028	14,400	14
Hartford, Conn.	Yes [g]	1964	Metcalf & Eddy, Boston, Mass.	[b] 62,178	197,819	15
Henderson, Ky.	Yes	1953	J. Stephen Watkins, Lexington, Ky.; Robt. E. Martin, Louisville, Ky.	16,892	16,890	16
Huron, S. Dak.	Yes	1962	Schoell & Madson, Hopkins, Minn.	14,180	14,000	17
Iowa City, Iowa	Yes	1963	Veenstra & Kimm, Des Moines, Iowa	33,443	33,000	18
Kansas City, Kans.	Yes	1953	Truman Schlop, Kansas City, Kans.	121,901	107,000	19
Kansas City, Mo.	Yes	1958	Black & Veatch, Kansas City, Mo.	475,539	449,500	20
Kendallville, Ind.	Yes	1963	Clyde E. Williams & Associates, South Bend, Ind.	6,765	6,765	21
Lafayette, Ind.	Yes	1963	Henry B. Steeg & Associates, Indianapolis, Ind.	42,330	42,000	22
LaPorte, Ind.	Yes	1962	Charles W. Cole & Son, South Bend, Ind.	21,157	21,000	23
Lathrup Village, Mich.	Yes	1957	Ayres, Lewis, Norris & May, Ann Arbor, Mich.	3,556	[e] 3,500	24
Louisville, Ky.	Yes	1963	Metcalf & Eddy, Boston, Mass.	390,639	415,495	25
Manchester, N.H.	Yes	1962	Fay, Spofford & Thorndike, Inc., Boston, Mass.	88,282	62,000	26
Massena, N.Y.	Yes	1946	William S. Lozier Co., Rochester, N.Y.	15,478	15,785	27
Michigan City, Ind.	Yes	1962	Boyd E. Phelps, Inc., Michigan City, Ind.	36,653	36,655	28
Milwaukee, Wis.	Yes	1957	Alvord, Burdick & Howson, Chicago, Ill.	741,324	967,700	29
Minneapolis, Minn.	Yes	1960	Toltz, King, Duvall, Anderson & Associates, Inc., Minneapolis, Minn.	482,872	1,041,700	30
Mishawaka, Ind.	Yes	1962	Charles W. Cole & Son, South Bend, Ind.	33,360	34,000	31
Mission Twnshp. Main Sewer District No. 1, Kan.	Yes	1959	Black & Veatch, Kansas City, Mo.	N/A	60,000	32
Napa, Calif.	Yes	1961	George S. Nolte, Palo Alto, Calif.	22,170	30,000	33
Nashville and Davidson, Tenn.	No			170,874	170,875	34
New Haven, Conn.	Yes	1962	Genovese & Cahn, New Haven, Conn.	152,048	178,200	35
New York, N.Y.	Yes	1959	Greeley & Hansen, Chicago, Ill.	7,710,346	8,137,000	36
Omaha, Nebr.	No			301,598	243,055	37
Oswego, N.Y.	Yes	1946	William S. Lozier Co., Rochester, N.Y.	5,417	6,860	38
Portland, Maine	Yes	1958	Metcalf & Eddy, Boston, Mass.	72,566	65,000	39
Portland, Oreg.	No			372,676	384,000	40
Providence, R.I.	No			242,878	226,358	41
Pueblo, Colo.	Yes	1963	Ken R. White, Denver, Colo.	91,181	100,000	42
Redding, Calif.	Yes	1956	Clair A. Hill & Associates, Redding, Calif.	12,773	13,175	43
St. Joseph, Mo.	Yes	1953, 1955, 1960,	Black & Veatch, Kansas City, Mo.	79,673	58,900	44

See footnotes at end of table.

Questionnaires. Where Necessary, Information Taken From "1962 Inventory Municipal Waste Facilities"

Line No.	Type sewers and population served, if available			Type of treatment	Treatment facilities designed for		Population equivalent (BOD) P.E.		Average flow (mgd)
	Separate	Combined	Separate and combined		Average flow (mgd)	P.E. (1,000's)	Untreated waste	Treated waste	
1	X	X	X	None	N/A	N/A	N/A	N/A	N/A
2	X	X	...	Trickling filter and primary (2 plants).	3.95	41.5	N/A	N/A	N/A
3	[b] 39,000	[h] 28,000	X	Primary	[h] 9.0	[b] 90.0	[h] 50,314	[h] 28,400	[b] 4.4
4	...	...	X	None	N/A	N/A	N/A	N/A	N/A
5	30,000	50,000	50,000	Primary plant and activated sludge plant.	42.0 3.5	420 35	206,000 6,200	167,500 755	12.9 0.58
6	X	X	X	14 plants—8 activated sludge, 5 trickling filter, 1 primary	N/A	1,269.4	[e] 7,975,000	[e] 781,600	[e] 1,263
7	X	...	...	None	[f] 3.5	[f] 35.0	[e] 47,000	[e] 47,000	[e] 1.320
8	[e] 636,200	[e] 636,200	...	3 plants—2 activated sludge, 1 primary.	213.1	1,540	1,562,000	349,000	[e] 228
9	...	...	X	None	...	...	N/A	N/A	N/A
10	X	...	X	Trickling filter (2 plants)	30.0	220	391,800	98,000	26.1
11	X	...	X	Activated sludge	6.0	50.0	28,210	13,035	4.7
12	...	[h] 45,000	...	Trickling filter	10.0	150.0	170,000	51,000	12–13
13	X	X	...	Activated sludge	3.0	30.0	43,600	3,130	3.48
14	X	...	...	Primary	3.0	30.0	18,000	[e] 11,830	1.8
15	X	[h] X	X	....do	43.5	360.0	N/A	N/A	41.0
16	...	X	...	Primary [i]	7.2	31.0	N/A	N A	N/A
17	X	...	...	Trickling filter	3.0	37.5	42,700	8,600	2.5
18	X	...	...	....do	4.0	35–45	33,800	6,200	4.0
19	X	[h] X	...	None	...	...	649,000	649,000	51.7
20	X	X	...	None [j]	115.0	1,550	730,100	729,650	N/A
21	X	X	...	Trickling filter	1.44	7.7	[e] 6,765	N/A	0.96
22	...	X	...	Primary	9.0	60.0	19,825	12,530	4.65
23	...	X	...	Trickling filter	6.0	60.0	19,500	3,600	3.21
24	...	...	[h] X	Enters Detroit system	...	...	N/A	N/A	N/A
25	X	X	...	Activated sludge (8 plants)	102.88	524.61	N/A	N/A	N/A
26	...	62,000	...	None	...	...	N/A	...	N/A
27	...	X	...	Primary	6.0	N/A	N/A	N/A	2.5
28	...	X	...	Activated sludge	10.0	38.0	43,260	3,730	7.8
29	X	X	...	....do [k]	155.04	N/A	2,380,250	190,055	187.325
30	247,580	[h] 187,000	...	Primary	134.0	910.0	1,630,000	1,110,000	145.0
31	...	...	X	Activated sludge	8.0	65.5	51,700	4,410	8.5
32	X	...	...	Trickling filter	16.0	70.0	[e] 60,000	[e] 9,000	6.0
33	X	...	...	....do	4.0	55.0	33,970	3,395	3.1
34	14,000	166,000	...	Activated sludge	54.0	556.0	356,000	171,000	38.05
35	X	[h] X	...	Primary (3 plants)	32.1	N/A	N/A	N/A	27.2
36	X	X	X	Activated sludge (11 plants) Primary (3 plants)	1,319.1	N/A	N/A	N/A	[l] 858.8
37	X	X	...	Activated sludge (1 plant) Primary under construction (1 plant)	72.04	243.4	N/A	N/A	N/A
38	X	...	X	4 plants—1 Activated sludge, 3 Primary.	0.82	N/A	N/A	N/A	1.18
39	...	...	X	None	...	...	...	...	N/A
40	52,000	[h] 332,000	...	Primary	60.0	500.0	520,164	331,000	73.45
41	...	...	X	Activated sludge	60.0	N/A	565,000	124,000	84.6
42	...	X	...	Trickling filter	30.0	200.0	[e] 110,000	N/A	N/A
43	X	...	...	Primary	2.01	18.5	N/A	[e] 14,800	1.8
44	...	X	...	None	...	...	144,780	144,780	[e] 15.0

See footnotes at end of table.

Table II.—Summary of Sewer and Treatment Information as Obtained From Engineering Reports and Question-

City	Engineer report		Engineer making report	Population (1960 census)	Estimated total sewered population	Line No.
		Date				
St. Paul, Minn	Yes	1960	Toltz, King, Duvall, Anderson, & Associates, Minneapolis, Minn.	313,411	282,070	45
Salem, Oreg	Yes	1960	Cornell, Howland, Hayes, and Merryfield, Corvallis, Oreg.	49,142	52,000	46
Seattle, Wash	Yes	1958	Brown & Caldwell, San Francisco, Calif	557,087	558,000	47
Sedalia, Mo	Yes	1956	Burns & McDonnell Engineering Co., Kansas City, Mo.	23,874	21,000	48
Spokane, Wash	No			181,608	120,000	49
Syracuse, N.Y	Yes	1961	O'Brien & Gere, Syracuse, N.Y	216,038	221,065	50
Tacoma, Wash	Yes	1957	Brown & Caldwell, San Francisco, Calif	147,979	150,000	51
Texas City, Tex	No			32,065	32,000	52
Utica, N.Y	Yes	1946	William S. Lozier, Rochester, N.Y	100,410	[n] 600	53
Washington, D.C	Yes	1957	Board of Engineers—S. A. Greeley, F. A. Marston, G. J. Requardt.	764,000	1,323,470	54
Yakima, Wash	Yes	1963	Cornell, Howland, Hayes, & Merryfield, Corvallis, Oreg.	43,284	N/A	55
Totals where applicable				[b] 20,000,000	[b] 23,000,000	56

[a] 1962.
[b] For portion reported only.
[c] As reported from municipality.
[d] Part of population served by other facilities.
[e] Estimated.
[f] Proposed.
[g] In preparation.
[h] Separation program underway.
[i] Built since date of report.
[j] Two primary plants under contract.

dry weather sanitary discharge is produced by a rainfall intensity of approximately 0.01 in./hr. after impervious surfaces are wetted. By combining this relationship with the probability of rainfall occurrence, the proportion of sewage that will escape through overflow structures for any given capacity of the interceptor was determined. When the flow in the sewers is twice the average dry-weather flow approximately 2.7 percent of the total annual flow of domestic sewage may be expected to overflow to the receiving stream. The basic data for this study were developed for low intensity, prolonged rains but were projected to include high intensity storms. During storms the percentage of sewage lost by overflow would be quite high. For instance, in a storm intensity of only 0.1 in./hr., 82 percent of the sewage during the storm would overflow from a system designed for twice the dry-weather flow, and if designed for three times the dry-weather flow the same storm would allow the overflow of about 73 percent. For storms of 0.5 in./hr., the overflow would be 97 and 94 percent, respectively. Thus, even with a comparatively light rainfall, significant pollution in terms of organic load and bacterial contamination will be discharged directly into the watercourse. Even with interceptors designed to collect flows as great as 9 times the dry-weather flow, 82 percent of the sewage would be overflowed from storms of 0.5 in./hr. McKee concluded that design of interceptors sufficiently large to provide protection of the streams was not economically feasible.

McKee also brought out the significant fact that, although the total percentage of sewage lost is low in the Boston area, the frequencies of storms causing high loss of sewage to the streams is far too high for adequate protection of receiving water. He found that for interceptors designed for 1.5 to 3 times average dry-weather flow, overflows may be expected 5 to 6 times per month in the summer, which is much too frequent for waters to be used for bathing or shellfish propagation.

Camp (3), in recognizing the public health problem of discharging high quantities of pathnaires. Where Necessary, Information Taken From "1962 Inventory Municipal Waste Facilities"—Con.

Line No.	Type sewers and population served, if available				Treatment facilities designed for		Population equivalent (BOD) P.E.		Average flow (mgd)
	Separate	Combined	Separate and combined	Type of treatment	Average flow (mgd)	P.E. (1,000's)	Untreated waste	Treated waste	
45	16,900	265,170	....	Primary..................	134.0	910.0	1,630,000	1,110,000	145.0
46	X	....	....	....do.[m]................	49.5	450.0	286,000	212,000	11.2
47	94,000	464,000	....	Activated sludge (3 plants).	10.1	71.2	558,030	501,100	N/A
				Primary (2 plants)..........	N/A	35.5	558,030	501,100	N/A
48	X	....	....	Trickling filter (3 plants)....	2.6	27.7	[e] 95,000	[e] 9,500	2.35
49	....	120,000	....	Primary..................	40.0	176.0	250,000	175,000	19.86
50	X	X	....	.....do..................	27.5	200.0	N/A	N/A	42.0
51	....	....	[h] 150,000	Primary (2 plants)..........	27.0	100.0	150,000	123,000	[n] 16.75
52	[e] 24,000	[e] 8,000	....	Trickling filter (1 plant)....	2.5	25.0	[e] 8,850	[e] 1,320	[e] 2.25
				Activated sludge (1 plant).	0.8	1.3	[e] 380	[e] 160	[e] 0.11
53	X	X	....	Primary (1 small plant)....	0.3	2.0	N/A	N/A	N/A
54	....	....	[h] X	Activated sludge..........	290.0	1,791.0	1,200,000	[e] 290,000	180.8
55	X	X	....	Primary..................	11.0	82.8	93,000	60,500	4.6
				Trickling filter (3 small plants).	N/A	N/A	N/A	N/A	N/A
56	.9	10	36	No treatment—9 [r]........ Primary—25 [r]............ Secondary—[r]30	([s])	([s])	([s])	([s])	([s])

[k] Plus 1 very small trickling filter plant.
[l] Incomplete—data not available for 2,327,000 population.
[m] Extension to secondary plant underway.
[n] Does not represent total for community.
[p] Estimated to nearest million.
[r] Includes multiple plants in several communities.
[s] Incomplete data do not allow for valid totals.

ogens into watercourses by combined sewer overflows, concluded from studies at Concord, N.H. and by reviewing others' work, that chlorination in amounts of not more than 10 times the average dosage required for dry-weather flow should be applied to combined overflows.

Palmer (4), in studies at Detroit to support the installation of combined sewers, disagreed with conclusions of others that the quality of stormwater from a combined sewer shows high pollution during the early period of overflow, but he did not substantiate this opinion with data. However, samplings of stormwater alone from a catch basin indicated a high first flush of contamination. First samples contained coliform MPN's of 930,000 per 100 ml and BOD of 234 mg/1 while samples three hours later had MPN's of 25,000 and BOD of 96 mg/1. Palmer (5) later obtained similar results in sampling stormwater from several catch basins. In this work Palmer also substantiated McKee's findings on frequencies of overflows during summer months as did Johnson (6) in Washington, D.C.

Camp (7) believes that the only completely satisfactory solution to the problem of pollution by combined sewer overflows is the complete elimination of the combined overflows but he feels that, in view of the enormous cost, some consideration may be warranted to proceed with the compromise of partial separation as a first step.

Riis-Carstensen (8) verified the data of McKee in Buffalo and added a method of compensating for variables in population density and runoff coefficient.

Shifrin and Horner (9) in St. Louis found the sewage discharged by combined sewer overflow to vary from 2.23 to 3.09 percent of total annual flow.

In Washington, D.C. it was estimated that an average of 3.3 percent, or 3.6 mgd of sewage, is lost by overflow from combined sewers (10). Johnson (11) presented data which showed that in Washington, D.C., at several overflow points the average number of overflows varied from 5 to 16.8 per month in the summer and from 3.8 to 4.7 per month in the winter.

Others who agree with these findings are Greeley and Langdon (12) in studies of New York City; Benjes *et al.* (13) at Kansas City, Mo.; and Gameson and Davidson (14) at Northampton, England.

Data From Engineering Reports and Completed Questionnaires

The first attempt to consolidate information on the quantity and quality of these overflows was made by examining the 50-odd engineering reports and questionnaires. The questionnaires were designed to obtain such data; therefore, the appropriate portions were compiled from this source (table III).

In all, 39 municipalities revealed information to some degree relating to the desired objective, although the generally known fact was further confirmed that only scattered and incomplete information is available. This lack of specific information is understandable because the complexities inherent in a collection system, even in a small community, make it necessary to carry on a comprehensive, time-consuming, and expensive study to obtain the kind of data needed for a thorough evaluation.

1. *Quantity of Combined Overflows and Stormwater*

Because data from the engineering reports were lacking or incomplete regarding quantities of combined sewer overflows, the information from published reports (2) (3) (4) (5) (6) (7) (8) (10) (11) (12) (13) (14) was used for estimation purposes. These reports generally confirmed the introductory statement that from 3 to 5 percent of untreated wastewater annually reaches watercourses by combined sewer overflows but that up to 95 percent of such wastewater overflows during storms. Estimates here for annual amounts will be con-

Table III.—Summary of Characteristics of Combined and Stormwater Sewer

City	Pollutional load expected at times of overflow (P.E.)		Number of		Combined sewer overflow			Line No.
					Water uses which may be or are affected			
	Treated	Untreated	Points of overflow	Bottlenecks	Use [a]	Degree [b]	Dollar loss	
Amsterdam, N.Y.			30	Numerous	12			1
Ashland, Ky			1		1			2
Atlanta, Ga	19,200	48,000	1	1	1,2,3, 4,5,7, 8,9,10, 12,13	mi-gr		3
Boston, Mass			48	Throughout main system.	4,5,13			4
Chattanooga, Tenn		100,000	20	*	1–13	mi-mo	([d])	5
Chicago, Ill		[f] 8,400,000	362	Many	1,3,4, 5,8,9, 10,11, 12	mi-gr		6
Cleveland, Ohio			420	Entire system.				7
Des Moines, Iowa			Many	Many	1	mo		8
Elmhurst, Ill			9	29				9
Eugene, Oreg			3		5,7,8	mi-mo		10
Findlay, Ohio				Many				11
Hartford, Conn			80–100	N/A	3,4,5, 7,8,9, 10,11	mi-gr	Sport fishing 22,000 man-days.	12

See footnotes at end of table.

fined to the conservative side of the range at 3 percent overflow. If it is assumed that domestic wastewater contribution averages 100 gpd, then the annual overflow of untreated waste would amount to 28 billion gallons from the 25.85 million people served by combined sewers only. Because some of the waste from the 33 million people served by combined and separate systems would not be subjected to overflow during storms, the total overflows from this source would be something less than the 36 billion gallons per year which might be lost by overflow if no separate systems were included. However, it is estimated that the majority of these 33 million people are affected by combined systems. This would indicate, then, that the total annual overflow would be somewhat less than 64 billion gallons but probably not much less. In other terms this would be equivalent to untreated waste from nearly 1.75 million people. It is important to recognize that these amounts represent only the amounts of sanitary wastewater which normally should go to a treatment plant. The enormous amounts of stormwater are added to these quantities.

Quantities of stormwater alone discharged by sewers vary so greatly in different areas, as do the amounts running off, that it is difficult to estimate the totals without special studies for this purpose. Added to this is the fact that, after a system is designed and installed, there is little evidence of volume measurements of total stormwater flow. Rainfall records can be used but actual runoff coefficients would have to be determined along with a study of the sewer system to establish a reliable basis for estimation. The influence of infiltration also must be included.

However, some idea of the amounts of surface runoff from storms may be obtained from certain assumptions. If the impervious area is assumed to be one-third of the total for an urban community served by sewers, then for each acre there will be about 9,000 gallons of stormwater

Overflows as Compiled From Engineering Reports and Questionnaires

Line No.	Combined sewer overflow—Continued			Miles of stream affected	Stream studies completed	Benthos studies completed	Sludge banks in evidence	Biochemical Oxygen Demand	Suspended Solids
	Damages attributable								
	Damage [c]	Degree [b]	Dollar loss						
1	1,7	....	....	....	Yes.....	....	Yes.....	....	....
2	....	....	....	....	....	....	....	....	....
3	1,2,3, 4,5,6, 7	mi-gr.....	5—loss of industry $6–$10 million.	20.........	Yes.....	....	Yes.....	....	....
4	2,7	....	....	....	Yes.....	No.....	Yes.....	....	....
5	1–7	mo-gr....	(e)	25.........	Yes.....	....	Yes.....	....	....
6	1,4,6, 7	....	....	....	....	Yes.....	Yes.....	....	....
7	....	....	....	....	....	....	....	1,701,000 lbs in 1961.	....
8	1,2,3	mo-gr....	....	....	....	....	....	....	....
9	1	xc......	....	....	....	....	....	....	....
10	1,2	mo, mi ..	....	....	....	....	No.....	....	....
11	1,2,3	mo-gr....	....	....	....	....	....	....	....
12	....	....	....	....	....	....	....	....	....

See footnotes at end of table.

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Table III.—Summary of Characteristics of Combined and Stormwater Sewer

City	Pollutional load expected at times of overflow (P.E.)		Number of		Combined sewer overflow			Line No.
					Water uses which may be or are affected			
	Treated	Untreated	Points of overflow	Bottlenecks	Use [a]	Degree [b]	Dollar loss	
Henderson, Ky			10		13			13
Huron, S. Dak			3	2				14
Kansas City, Kans			20					15
Kendallville, Ind				Many				16
LaFayette, Ind			2	do.				17
La Porte, Ind				21				18
Louisville, Ky								19
Michigan City, Ind				Many				20
Milwaukee, Wis			168 storm-water. 131 com-bined.	do.				21
Minneapolis, Minn		([g])	>100		1,2,3, 7,8,9, 11,12, 13	mi-gr		22
Mishawaka, Ind			23	8+				23
Mission Twnshp. Main S. D. No. 1, Kans.								24
Nashville, Tenn								25
New Haven, Conn			21	Many				26
New York, N.Y		([h])	218±		4,5,6,			27
Portland, Maine			18	None	4,6,11			28
Portland, Oreg			165	Many	3,4,5, 7,8,9, 11,12, 13	mi-gr		29
Pueblo, Colo			*	do.				30
Redding, Calif			7	do.	1,4,5, 8,10, 13	mi-gr		31
St. Joseph, Mo								32
Salem, Oreg			20	4				33
Seattle, Wash			~100	Many	4,5,6, 7,8,12, 13	mi-gr	([j])	34
Sedalia, Mo				General				35
Syracuse, N.Y			86	Many	3,7			36
Tacoma, Wash			7		4,5,8, 11,12	mi-gr		37
Texas City, Tex			At each man-hole.					38
Washington, D.C			~80	Many	3,4,5, 7,8,10, 11,13	mi-gr		39

[a] Uses and corresponding numbers assigned as follows: domestic water supply—1, commercial water supply—2, industrial water supply—3, bathing—4, swimming—5, shellfish—6, commercial fishing—7, sport fishing—8, power—9, irrigation—10, shipping—11, fish and wildlife—12, aesthetic—13.

[b] Degree assigned as follows: minimal—mi, moderate—mo, great—gr, and excessive—xc.

[c] Damages and corresponding numbers assigned as follows: basement flooding—1, nuisances—2, property damage—3, real estate values—4, use restricted—5, increased treatment cost—6, recreational use impaired—7.

[d] Rough estimates of values as follows: domestic water supply—$50 million, commercial water supply—$5 million, industrial water supply—$10 million, bathing—$1 million, swimming—$1 million, shellfish—$5 million, commercial fishing—$5 million, sport fishing—$5 million, hydroelectric power—$100 million, irrigation—$5 million, commercial shipping—$100 million, fish and wildlife—$10 million, aesthetic—$10 million.

[e] Rough estimates of values as follows: basement flooding—$0.5 million, nuisances—$0.5 million, property damage—$1 million, real estate values—$2 million, use restricted—

Line No.	Combined sewer overflow—Continued: Damages attributable: Damage [a]	Degree [b]	Dollars loss	Miles of stream affected	Stream studies completed	Benthos studies completed	Sludge banks in evidence	Biochemical Oxygen Demand	Suspended Solids
13	1,4	mo-gr...	...	...	...	...	...	...	...
14	1,3	...	...	...	...	...	...	...	...
15	1,2	mo-gr...	...	...	...	...	...	...	...
16	1,2	...	...	...	...	...	...	...	...
17	1,2,3	mo-xc...	...	...	...	...	...	...	...
18	1,2,4	mo-gr...	...	...	...	...	...	...	...
19	1,3	...	...	...	...	...	...	...	...
20	1	...	...	...	...	...	...	...	...
21	1	mo-gr...	...	...	...	...	...	...	...
22	1,2,7	mo-gr...	...	...	...	...	...	...	...
23	1	mo-gr...	...	...	...	...	...	...	...
24	1,3,4	mo-gr...	...	...	...	...	...	...	...
25	1,6	gr, xc	...	...	...	...	...	92 mg/1 172,000 lbs./doy.	72 mg/1 22,720 lbs./doy.
26	1	...	...	...	...	...	...	...	...
27	1,4,7	mo-gr...	...	...	...	...	...	...	...
28	1,2,3,7	mi-gr...	...	...	Yes...	...	Yes...	...	...
29	1,2,3, 4,5,6,7	mi-mo...	...	12	...	...	No...	...	...
30	1,2	mo ...	...	...	...	...	...	...	...
31	1,2,3	...	...	...	...	...	...	...	...
32	1,3	mo...	...	...	...	...	...	...	...
33	1,2	mi...	...	To Portland horbor.	Yes...	...	No...	...	...
34	1,2,3, 4,5,7	mi-gr...	([k])...	30	Yes...	Yes...	Yes...	...	...
35	1,3	...	...	...	...	...	...	...	...
36	...	...	...	...	...	...	...	...	...
37	1,2,3	mi...	...	0	Yes...	Yes...	No...	...	...
38	...	...	...	0	...	...	...	...	...
39	1,2,7	gr...	...	...	...	...	...	...	...

$2 million, increased treotment costs—$1 million, recreotional use impaired—$2 million.

[f] Average per yeor.

[g] Estimated tc be 0.6–3.5 percent of BOD reaching point of diversion; also plant byposs amounts to 1.7–3.1 percent of BOD reaching treatment plont, ond loss of BOD from selected regulotors varies between 0.06 and 3.5 percent of BOD reoching treotment plant. Total amount in terms of weight unknown.

[h] Estimated that 2.6–3.1 percent of total raw wostewoter discharged by overflow with stormwoter.

[j] Under the fishing category the total summer value assigned was $1,120,000/yr.

[k] Maximum damage estimated as caused by basement flooding—$1500—$2,000/house.

* Many exist but exoct number could not be determined.

for each inch of rainfall. This amounts to about 5.8 million gallons for each square mile for each inch of rain. In the 50 States there are some 11,400 communities of all sizes, having a total area of 43,100 square miles. The area of the 1,943 communities discussed in this report is not known; therefore, projections cannot be made for these totals. As a specific example, though, Chicago with 190 square miles of sewered area serving 3.5 million people would, under these assumptions, have a stormwater runoff of 1.1 billion gallons for each inch of rain. Similar projections can be made for other communities.

For these reasons no overall estimate of amount of stormwater is included. Some of the details are discussed in the special studies sections.

2. *Damages Attributed to Stormwater*

Although many cities realize the need for comprehensive studies of the stormwater problem, adequate funding most often is not available; therefore the studies contracted for are limited to the pressing needs most apparent to the public. This is clearly documented in the reports studied, as shown in table IV, which delineates the importance of damages in the opinion of the investigating engineers and the communities.

Table IV.—Damages Attributed to Combined Sewer Overflows as Shown by Data Obtained from 35 Communities

Damage	Number communities reporting	Relative degree of damage
Public health—basement flooding.	33	Minimal—excessive.
Nuisances	19	Minimal—excessive.
Property damage—houses, boats, etc.	15	Minimal—great.
Real estate values	9	Minimal—great.
Use restricted	4	Minimal—great.
Increased treatment cost	5	Moderate—excessive.
Recreation area use impaired.	11	Minimal—great.

By far the most frequent problem discussed is that which occurs when combined sewers surcharge and residence and business basements are flooded with a combination of untreated sewage and stormwater. This not only causes a nuisance and a financial loss but is an obvious public health hazard. Since 33 of the 35 communities reporting damages stressed this problem, it appears that basement flooding was a primary factor in their authorizing the studies. This is confirmed by discussion in the reports, some of which contain strong language on this point. Closely related to basement flooding, but not included as an item in the questionnaire, is the problem of street flooding. Most of the communities reporting basement flooding problems also suffer street flooding.

Little attention was given to the public health aspect of such flooding although the reporting engineers no doubt realize that health hazards do occur each time untreated sewage backs up into basements or streets.

Only two cities reported on the quality of overflows, which may or may not be of similar quality to the waste waters entering basements. This lack of data is believed traceable to the fact that where excessive flooding occurs the physical evidence alone should provide sufficient stimulus for correction. Yet, many of these situations with their continuing health hazards persist. It appears of fundamental importance to the public that more information be obtained on the quality of these floodings and their health aspects.

Damages were classified in the tabulation. More than half of the situations studied considered overflows as nuisances and nearly half claimed damages to property. These assessments may be related to house and street flooding. About one-third related the damage to waterways in terms of recreational impairment.

Attempts were made by three cities to assign dollar values to the losses. One assigned values to each damage; another stated that a loss of industry resulted and that waste treatment costs were increased by $10 million. A third estimated the maximum damage caused by basement flooding to be $1500–$2000 per house.

Only seven cities mentioned the pollutional load imposed on streams at times of overflow and there is an apparent lack of uniformity in measuring this load. For instance, two cities reported the load in pounds of BOD at times of overflow; one reported total pounds BOD average per year; one gave a total weight for one specific year; one reported the loss as a percentage of the BOD reaching the point of diversion but did not include actual quality data, and one reported the total loss as a percentage of total raw wastewater. One city reported BOD and suspended solids data for combined sewer overflows. No other quality data were available.

Obviously more complete studies are needed to obtain meaningful quality information for overflows.

Altogether, 30 cities of the 39 supplying information tabulated or mentioned the number of points of overflow in the system. These varied from 1 to 420. Similarly, 25 communities reported bottlenecks in the system. A few counted the number of bottlenecks but most found this a difficult task and settled for a number described as "many."

3. *Water Uses Affected by Overflows*

Related to the assessment of damages by overflows was the tabulation of water uses potentially or actually impaired by combined sewer overflows. For discussion purposes these are grouped in eight general classifications. Information was available from 19 communities. The categories and number of communities considering each are as follows:

Fishing	14
Bathing and swimming	13
Water supply	11
Aesthetic	9
Fish and wildlife	8
Commercial shipping	8
Hydroelectric power	6
Irrigation	6

This tabulation shows that recreational, commercial, and public health requirements are fairly evenly divided and that all are quite important in the opinion of the communities. Water uses were affected in varying degrees from minimal to great, with a relatively even scattering. One city estimated and reported dollar amounts for each use, while another valued sport fishing at 22,000 man-days, and still another placed a summer value on fishing affected at $1,120,000.

Few cities reported the length of stream affected. Only eight of the communities have made stream studies and only three have included benthos studies. Seven cities stated that there were sludge banks in evidence and four said there were not.

Data From Special Studies

Because the 50-odd engineering and community reports contained little real data on characteristics of combined and stormwater overflows, it was necessary to utilize the data from only a few cities where special investigations have been made and from which the information was made available. The areas studied were the East Bay Metropolitan Utility District, Oakland, Calif.; Chicago, Ill.; Cincinnati, Ohio; Washington, D.C.; and Los Angeles County, Calif.

The studies differed in pattern and background conditions and results therefore could not be consolidated as representative of conditions throughout the United States. Thus the data for each community are presented separately.

1. *East Bay Metropolitan Utility District*

Of the six cities connected to the wastewater treatment plant, only Oakland retains combined sewers, 5 in number, which are connected to the treatment facilities by diversion structures. These structures divert all the dry-weather flow into an interceptor and during storms permit bypass of stormwater-diluted wastewater through outfalls to San Francisco Bay.

In spite of the essentially separate collection system, wastewater flows in the interceptors increase substantially during storms. How the stormwater reaches the interceptors is not known, but it is presumed that rising groundwater (infiltration) and flow from connected roof leaders, catchbasins, basement sumps, and yard drains all contribute. Because the treatment plant will not accommodate the increased hydraulic load, it is necessary to bypass the plant during storms. Extensive sampling of the various features of the system was initiated because of the existing conditions.

Table V includes analytical data from two interceptors for periods of heavy rainfall and dry weather. The dilution effects of stormwater are apparent.

Table V.—Analyses of Interceptor Flow During Wet and Dry Weather at East Bay Metropolitan Utility District—All Data Are Average

Determination	South interceptor		North interceptor		Computed characteristics of wet weather flows to plant [1] (mg/1)
	Wet weather flow	Dry weather flow	Wet weather flow	Dry weather flow	
DO (mg/1)	4.9	0.5	5.5	0.8	5.0
Total sulfides (mg/1)	0	.3	.03	.1	.01
BOD (mg/1)	178	449	195	285	180
Chlorides (mg/1)	128	264	129	227	162
SS (mg/1)	162	336	162	....	128

[1] Based on proportions of 0.8 from south interceptor and 0.2 from north interceptor.

Table VI condenses the results of special sampling during storms to show the characteristics of combined sewer overflows, separate stormwater from storm sewers, stormwater from a creek not ordinarily receiving wastewater, and the treatment plant bypass. The indications are that the stormwater both in sewers and in creeks contain substantial pollutional loads as measured by organic and inorganic standards. Large numbers of coliform organisms also are present. The high degree of load imposed by combined sewer overflows is clearly shown. Since there is reason to believe that these results are fairly typical, the implication is that the overall organic and coliform loading to the Nation's receiving waters is enormous.

Another way of measuring the effect of stormwaters on watercourses is by examining conditions at pumping stations when it is necessary to bypass during storms. Table VII presents data from such situations. Samples were taken upstream and downstream from, and at, the station. At the same time samples were taken from a nearby stream which does not receive wastewater overflows. The organic and bacteriological quality of the water upstream from the discharge is approximately equivalent to that in the stream not receiving waste; however, the inorganic load imposed by erosion into the creek is apparent in the concentrations of solids and sand. The effect on the stream by the wastewater is clearly shown throughout the table; for example, the increase in BOD and coliform counts.

2. *Chicago, Illinois*

A special report on water quality in the Illinois River System, as requested by the Department of Justice, was prepared by the Public Health Service and published in January 1963 (15). The report was pertinent to the latest litigation concerning the diversion of Lake Michigan water at Chicago. In connection with this investigation a small project was

Table VI.—Characteristics of Combined Sewer Overflows, Storm Sewer Flows, Watershed Streams, and Treatment Plant Bypass at East Bay Metropolitan Utility District

Determination	Combined sewer overflows (14 samples from various stations)			Storm sewer flows (21 samples from various stations)			Creek samples from areas not receiving wastewater (five samples from various stations)			Treatment plant effluent bypassed in bay (sampling during nine different periods)		
	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average
DO (mg/l)	2.4	9.6	6.9	0	13.2	7.3	2.8	8.2	4.8	1.2	9.5	4.9
BOD (mg/l)	13	153	59	3	>700	87	<5	35	17	45	320	133
Total Solids (mg/l)	132	1,327	400	726	726	1,401	1,401	1,401	1,401	500	1,100	800
Vol. Solids (mg/l)	83	291	144	168	168	168	158	158	158	100	600	350
Susp. Solids (mg/l)	60	1,120	203	16	4,400	613	780	1,620	1,176	108	770	253
Coliform (MPN/ml)	2,300	2,400,000	293,000	4	70,000	11,800	130	62,000	13,800	62,000	>7,000,000	>1,408,000
Chlorides (mg/l)	619	619	619	300	10,260	5,100	540	540	540	......	....	....
Oil & Grease (mg/l)	8	66	33	2	162	32	0	100	25	12	255	133
Sand (mg/l)	0	276	76	7	868	158	193	1,074	560	106	116	111
pH	6.8	7.4	7.1	6.3	7.8	6.9	.....	.....	.....	......	....	....

Table VII.—Stream Quality Conditions at Time of Bypassing of Pumping Stations

Determination	Upstream			Point of discharge			Downstream			Another stream of receiving overflow		
	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Mavimum	Average
DO (mg/1)	7.8	10.0	9.5	7.8	10.0	8.9	7.2	9.9	8.5	7.0	9.6	8.3
BOD (mg/1)	<1	21	6.8	21	360	92	5	60	25	3	16	9.5
Total Solids (mg/1)	229	748	469	78	543	385	352	2,482	918	5,380	6,672	6,026
Vol. Solids (mg/1)	70	185	124	70	276	174	90	355	185	542	620	581
Susp. Solids (mg/1)	23	644	269	64	278	129	53	568	274	6,820	16,005	11,412
Coliform (MPN/100ml)	620	4,250	1,990	10,800	70,000	48,200	980	126,500	40,500	620	4,250	2,435
Temp. ° C	12.8	13	12.9	13.0	13.8	13.4	12.5	13	12.75	.....	....	....
Chlorides (mg/1)	16	26	21	26	46	36	18	24	21	12.5	12.5	12.5
Oil & Grease (mg/1)	0	15	9.2	5.2	33	17.1	5.8	13	10.5	15	15	15
Sand (mg/1)	0.0005	366	133	0	101	45	.0076	216	100	4,774	4,774	4,774
pH	7.3	7.5	7.4	7.2	7.6	7.4	7.3	7.7	7.5	.....	....	....

initiated to study combined sewer overflows in the Chicago area.

Since 1856, when the first combined sewers were installed to serve 7 square miles of the "Loop," the combined sewer system has been expanded to include more than 3,600 miles of sewers serving 190 square miles and 3.5 million people.

The total pollution load to Chicago watercourses by stormwater overflows from the combined sewer system has not been determined by field measurement. Estimates place the annual sanitary and industrial waste overflows to the canals in the range of 3 to 5 percent of total annual flows for sanitary sewage interceptors designed for 1.5 to 3 times the average dry-weather flow. However, it is pointed out that the first slug of such waste may be several times the strength of normal sewage flow.

To obtain on-site data, a small test site was studied with the intent of extending the data for full-scale estimates. The study area was designated as the Roscoe Street sewer, covering an area of about 8.6 square miles on the north side of the city. Interconnections between Chicago's major sewers serving adjacent drainage areas provide relief drainage for localized storms and also obtain economy of design. This often results in indistinct drainage boundaries. In this instance, about 2.4 square miles of the Roscoe Street area is connected to the Kostner Avenue sewer. For this study the interconnected area was assumed to be tributary to the Roscoe Street sewer. The impervious area was estimated to be 42 percent of the total area. Gaging and sampling during storm periods continued in this area throughout the study.

The study was carried on for a 9-month period, mostly in 1962, during which time there were 31 storms. The total BOD load discharged to the stream during this period was computed at 278,300 lbs., or an average daily amount of 1,010 lbs.

It was recognized that many factors could change these amounts but they were the best figures available to produce a simple projection for estimating the total BOD overflow load to the canal system. Flow data from three major treatment plants were used for the computation and on this basis the average total BOD overflow load was calculated to be 46,900 lbs./day, or a population equivalent of 281,400.

The report concluded that the discharge of raw sewage and industrial wastes mixed with stormwater during periods of storm runoff constitutes a significant intermittent source of pollution of the Chicago waterways. It points out the various damages to waterways and losses of use caused by stormwater overflows and adds, "More important, however, is the danger to public health from the pathogenic bacteria and viruses which may be present in raw sewage. Although the concentration of BOD and sewage solids, with exception of the first flush, may be reduced by dilution during runoff periods, the pathogens remain a serious menace to any public use of the streams receiving these discharges."

3. *Cincinnati, Ohio*

The preliminary results of a study on urban land runoff as a factor in stream pollution recently became available (16).

This study covered a 27-acre residential and light industrial drainage basin with separate sewers. The resident population is about 240, a density of 9 persons/acre as compared with the overall city density of 10/acre. The area contains single-family homes, several small apartments, stores, restaurants, a firehouse, church, and several other public buildings. The impermeable area is about 37 percent and the ground slope is 2 to 3 percent.

Stormwater was sampled for about 1 year. Table VIII shows the seasonal variations of the quality of the stormwater overflows, and table IX shows the effect of time in a given storm on the concentrations of constituents. The pollutional load was measured by BOD and COD is about equal to that expected from the effluent of a secondary sewage treatment plant, while the suspended solids are about the concentration found in raw domestic sewage. Nutrients are high. BOD is the only constituent that shows much change in relation to the season.

Table VIII.—Seasonal Variations of Constituents of Stormwater Overflows From a Study of a 27-Acre Area in Cincinnati, Ohio

Constituent	1962		1963		
	July–September	October–December	January–March	April–June	July–September
	Mean concentrations (mg/1)				
Suspended solids.	180	160	260	250	190
Volatile suspended solids	43	41	63	62	48
COD	110	84	110	100	100
BOD	30	28	12	19	15
NO_2–N	0.07	0.03	0.06	0.05	0.07
NO_3–N	.41	.26	.44	.44	.52
NO_3–N	.97	.79	.49	.82	.50
Organic N	1.2	1.9	1.8	2.0	2.0
PO_2	1.2	.81	.47	.66	1.1

Table IX demonstrates the flushing effect with time and is equally true for short- and long-duration storms.

Bacteriological examination of the stormwater revealed that coliform counts and fecal streptococci counts were rather high. Fifty percent of the coliform counts were in excess of 58,000/100 ml and 50 percent of the fecal strep counts were in excess of 20,500/100 ml. These results are of special significance in areas where the receiving water is to be used for swimming.

Table IX.—Mean Concentrations of Constituents in Urban Land Runoff vs. Time From a Study of a 27-Acre Area in Cincinnati, Ohio

Parameter	Time after start of runoff				
	0–15 minutes	15–30 minutes	30–60 minutes	60–120 minutes	120 minutes and over
	(mg/1)				
Suspended solids	390	280	190	200	160
Volatile suspended solids v	98	69	47	58	38
COD	170	130	110	97	72
BOD	28	26	23	20	12
Total Nitrogen—N	3.6	3.4	3.1	2.7	2.3
Phosphate PO_4 (total soluble as PO_4)	.99	.86	.92	.83	.63

A computation was made to compare stormwater to sanitary wastewater from the same area. In terms of the ratio of stormwater to sanitary wastewater the various components were as follows: suspended solids, 140 percent; volatile suspended solids, 44 percent; COD, 25 percent; BOD, 6 percent; PO_4, 9 percent; and total nitrate nitrogen, 11 percent.

The report emphasizes the fact that urban runoff is a significant factor in considering waste loadings from urban sources.

4. *Washington, D.C.*

Limited sampling was carried on over a period of about 1 year to obtain information about street runoff. Runoff was sampled at various catch basins during storms but no attempt was made to return to the same site later. Several samples were taken at each site during each storm. No attempt was made to correlate the information to the overall problem. Results are shown in table X. The concentrations found for BOD, chlorides, and suspended solids point to a substantial pollutional load from stormwater.

Table X.—Summary of Analytical Data From Selected Catch Basin Samples During Storms in Washington, D.C., 1959–63

Sample location	BOD (mg/1)			Chlorides (mg/1)			Suspended solids (mg/1)		
	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average
Catch basins at 11 locations	6	625	126	11	160	42	26	36,250	2,100

5. Los Angeles Flood Control District

The water Conservation Division of the Los Angeles Flood Control District has been interested for many years in the quality of stormwater for purposes of spreading onto land areas to obtain replenishment of groundwater supplies. Results of studies carried on during the 1932–34, 1957–58 and 1962–63 storm seasons are contained in an unpublished report (17).

Average results of the sampling programs are shown in table XI.

Table XI.—Average Chemical Quality Characteristics of Stormwater From Los Angeles County

Dates	DO (mg/1)	BOD (mg/1)	SS (mg/1)	CL (mg/1)
1932–34	6.4	6.9	7,330	20.4
1957–58	8.0	8.2	1,534	....
1962–63	7.5	16.1	2,909	19.9

The studies showed a steady increase in BOD for each of the three periods and inconclusive trends for other components measured. The sampling also showed the first flushing effect for BOD. In the early period of storms the BOD concentration of stormwater was as high as 70 mg/1 and then decreased as the storms progressed and leveled off to a range of 10 to 20 mg/1.

The 1962–63 studies showed that the first storm of the season was responsible for much higher coliform counts in the stormwater than were succeeding storms. Samples from the first storm contained coliform counts ranging from 380,000 to 1,100,000 per 100 ml at 6 stations, whereas the counts in later storms ranged from 800 to 80,100 per 100 ml. The conclusion reached was that the first storm flushed accumulated organic dirt rich in coliforms into the receiving waters.

Data From Studies by Others

Studies of stormwater runoff have been reported from time to time at various locations. These studies have been concerned with local problems and the methods vary somewhat with the individual communities.

Palmer (4) sampled catch basins during storms in Detroit in 1949 and again in 1960 (5). His conclusions made it clear that the studies were inadequate to provide a solution. He observed that in some instances the quality of the runoff became worse as the storm progressed and in others it became better, while in still others there was no apparent pattern.

Sylvester (18) in 1959 and 1960 sampled Seattle street gutters during storms and found that the highest constituent concentrations usually were found when antecedent rainfall had been low.

Riis-Carstensen (8) discussed an extensive program of gaging and sampling of combined sewer flow in Buffalo, N.Y. He computed that in 1 hour during a storm the combined sewage carried 28.4 times the normal amount of suspended solids. He also observed that any evaluation of the pollutional effect of combined sewage overflows based on volume alone may be grossly misleading because of the wide variation in constituent strengths.

In 1954, studies were made of surface runoff at Oxney, England (19) from a 611-acre estate with separated sewers. It was concluded that, on the basis of assumed treatment plant effluent levels of 20 mg/1 for BOD and 30 mg/1 for suspended solids, the separate system reduced the BOD loading on the stream, but increased the suspended solids loading by 6 or 7 times. Studies were made in Moscow in 1936 (20) of stormwater runoff and in Leningrad in 1948–50 (20) in an area of cobblestone streets.

Samples taken from 1945–48 from summer rainwater drainage from streets and parks in Stockholm, Sweden, were reported (21). Stormwater samples from residential, park, school, sports ground, business and flat areas in Pretoria, South Africa, were reported in 1961 (22).

A summary of the data accumulated from this work appears in table XII.

Table XII.—Summary of Quality Characteristics of Stormwater and Combined Sewer Overflows for Various Cities as Reported by Others

Constituent	Seattle (18)	Buffalo, N.Y. (8) Combined sewer overflow				Oxney, England (19)	Moscow, USSR (20)	Leningrad, USSR (20)	Stockholm, Sweden (21)	Pretoria, South Africa (22) Stormwater	
	Stormwater	Bird Ave.		Baily Ave.		Stormwater	Stormwater	Stormwater	Stormwater	Residential, park, sports ground	Business and flat areas
		Before storm	During storm	Before storm	During storm						
BOD (mg/l)	10	162	100	127	121	100 max.	18–285	36	17–80	30	34
COD (mg/l)	...	...	...	...	...	...	...	...	18–3100	29	28
Total solids (mg/l).	...	498	754	461	785	...	...	...	30–8000	...	...
Susp. solids (mg/l).	...	158	544	126	436	2,045	1,000–3,500	14,541	...	...	...
Coliform (MPN/100ml).	16,000	...	...	...	...	...	...	...	40–200,000	240,000	230,000
Org. N (mg/l)	9.0 max	...	...	...	...	...	...	...	...	5.4	3.5
NO_3–N (mg/l).	2.8 max	...	...	...	...	...	...	...	...	...	...
Soluble P (μg/l).	784 max	...	...	...	...	...	...	...	...	...	...
Total P (μg/l)	1,400 max	...	...	...	...	...	...	...	...	...	...
Fixed residue (mg/l).	...	...	...	...	...	...	...	...	210–2420	...	...
Dissolved solids (mg/l).	...	108	...	...	...	...	...	...	...	228	154
Volatile solids (mg/l).	...	...	...	...	...	...	...	...	...	...	...
Chlorides (mg/l).	...	...	...	...	...	...	...	...	...	...	...

Additional Data From Municipalities

The questionnaire used in the present study was designed to incorporate comprehensive data on all aspects related to the combined sewer and stormwater overflows. Because of the many different objectives of the reports studied, many questions were wholly or partially unanswered. Some of the points which were brought out are discussed in the following sections.

Land Use

One of the fundamental types of data required in the design of a stormwater or combined sewer system is detailed knowledge of land use. This involves the various use classifications; i.e., residential, commercial, streets and alleys, etc., and the proportion of each area which is impervious. Conversely, the facts are needed also to understand and make intelligent correlations with other data about existing systems. Only scattered and mostly incomplete information was available for land use. For instance, 10 cities gave some data but only 1 had detailed information. This information has quite limited usefulness and is therefore not tabulated.

Basic Data and Hydraulics for Interceptors

Only scattered and incomplete data were given for most of the 12 cities which included information. For example, only one city included runoff coefficients with the other statistics. The many different conditions encountered in each city suggest detailed analyses of individual cities' problems, especially in regard to the complexities of interceptors. To compile and correlate meaningful data on interceptor design and discharge, which would be useful throughout the United States, appears beyond the scope of a preliminary report.

Stream Quality

Again, only a few reports contained stream quality data and those which did made no attempt to correlate the pollutional discharge with quality of the stream. This is understandable because most of the reports are preliminary and, if recommending treatment, base the requirements on something less than a detailed stream survey. The data as provided are discussed earlier in connection with table III. Other information has been discussed in connection with the special reports, except that which follows.

In Chicago it was estimated that an average total of 8.4 million pounds of BOD per year are discharged as the result of overflows in storms. This compares with 46.9 million pounds BOD as secondary treatment effluent, and 4.0 million pounds BOD as primary treatment effluent.

Minneapolis reports the BOD load resulting from storms in percentages. This discharge was estimated at 0.6 to 3.5 percent of the BOD reaching the points of diversion; however, the concentration at the points of diversion was not available. Minneapolis further estimates that the plant bypass due to storms amounts to 1.7 to 3.1 percent of the BOD reaching the treatment plant; and the BOD discharged from selected regulators varies between 1.7 and 3.1 percent of the BOD reaching the treatment plant.

Others such as Chattanooga, Tenn.; Cleveland, Ohio; Hartford, Conn.; Manchester, N.H.; Salem, Oreg.; Syracuse, N.Y.; Utica, N.Y.; and Yakima, Wash., determined dissolved oxygen, BOD, and coliform counts above and below the point of discharge.

There are much published data relating the effects of sanitary sewage, both treated and untreated, to stream quality, but very little about the effects of stormwater on streams. The special studies discussed earlier point out some of these information deficiencies.

The increasing amounts of stormwater from the ever increasing urban populations have serious public health overtones, particularly in view of the lack of valid information. The water uses adversely affected and the physical damages as earlier discussed further emphasize the problem. Overflows during heavy and prolonged storms, estimated to contain as much as 95 percent of the sanitary sewage, reinforce the belief that combined sewer systems now present a very real pollution hazard.

Rainfall and Effects on System

Factors relating rainfall and its effects on the collection system are considered in detail in the design of the sewers.

One of the most common methods of design of storm sewers is by the so-called rational method represented by the formula $Q=CiA$, wherein Q is the runoff rate in cfs, C is a selected coefficient of runoff expressed as the ratio of runoff to rainfall, i is the mean intensity of rainfall in in./hr., and A is the tributary area in acres. Judgment is needed in establishing values for C. Considerable judgment also is needed in using the rainfall data. For instance, it is necessary to establish the period or recurrence interval during which each section of a given facility will be called on at one time or another to carry a storm flow equal to or in excess of its capacity. At this frequency, surcharge or local flooding will result. General flooding would result in the event of a prolonged high intensity rainfall which exceeds the intensity for the design frequency. Many factors are considered in the selection of a design frequency; for example, economic implications of local flooding; type, nature, and extent of areal development which might be subject to damage by flooding; magnitude of applicable rainfall intensities; size or extent of tributary area; and economics of construction.

Design of combined sewers frequently is based on the same storm flow considerations as for storm sewers, except that they are sized to overflow beyond some factor of the dry-weather flow, frequently two to three times.

Usually an assumption is made to establish the amount of rain which will fall before runoff occurs. This amount is attributed to the wetting of surfaces, filling of depressions in impervious surfaces, retention on vegetation, infiltration into the soil, and surface detention required to build up a film of water sufficiently thick to cause flow. This assumption is a guess at best, but establishes a base from which runoff amounts are computed. These assumed rainfall amounts range from 0.01 to 0.04 in./hr.

Many measurements have been made of overflows occurring from combined systems and the dilution factors at the overflow points, but measurement of the actual quantities overflowed in relation to rainfall intensities and duration, along with frequencies and analytical data of the amounts overflowed, is lacking in the engineering reports. This again made it necessary to use the limited data from the special studies.

Metering of Flow and Regulatory Devices Used on Combined Systems

Of the more than 50 reports examined, only 15 indicated that the wastewater is or had been metered. Undoubtedly many others have made spot checks or even special studies. To appraise the problem fully, a more comprehensive metering arrangement would be necessary than that permitted by spot checks.

The use of regulating devices in combined systems was indicated by 21 cities. The types and numbers, where available, are shown in table XIII.

This sampling shows that the regulator types are fairly evenly divided between leaping devices, side weirs, and gates, with 7, 8, and 11

Table XIII.—Types of Sewage Flow Regulators in Use in Combined Systems From Cities Studied

City	Leaping devices	Side weirs	Gates	Siphons	Mechanical means	Other	Condition or remarks
Atlanta, Ga						2 drop inlet interceptors.	Good.
Chattanooga, Tenn	2				9		Leaping devices—poor. Mechanical—good.
Chicago, Ill			X				
Cleveland, Ohio	60	55	19	0	14	14 perpendicular weirs. 200 unclassified [a]	4 percent need repair at one time.
Eugene, Oreg		2					Good.
Hartford, Conn		80–100					
Huron, S. Dak	X		X				
Kansas City, Mo		X					
Manchester, N.H	1	6	4				
Minneapolis, Minn	20	X	X		X	17 float operated 24 orifices.	Constant maintenance required.
Mishawaka, Ind			X				Poor.
Mission Township, Main Sewer District No. 1, Kans.						Electrically-operated valves.	New.
Nashville, Tenn				2	19		Good.
New York, N.Y			X				Large number of regulators in use.
Portland, Maine	18		X				Good.
Portland, Oreg						Overflow weir	
Salem, Oreg			20				Good.
Syracuse, N.Y	X		Valve and float-controlled.			Dams and orifices	
Tacoma, Wash		X	X				
Texas City, Tex		X					Good.
Washington, D.C			X			Orifice	Total of 86, mostly orifice.

[a] Estimated to be 100 side overflows and 100 perpendicular overflows.
X Devices in use but in unknown numbers.

cities respectively using the three types. Orifice-types were indicated to be in use in quantity in several of the larger cities. Many cities use combinations of types.

There is insufficient information to evaluate the various types as to best choice for the purpose. Undoubtedly, performance is improved by proper maintenance of regulating devices and by providing designs which tend to balance flow conditions throughout a system. There are many instances of surcharging at points of regulation in dry weather due to poor design or maintenance or because changes in the system have rendered an existing regulator essentially useless.

Infiltration

A major problem in many collection systems is infiltration. In this discussion, infiltration includes that water entering a sewer system by way of defective joints, cracks, breaks, or from manhole sites.

In the early years of sewer design and construction, experience proved that large amounts of water infiltrated all types of sewers. Accordingly, design criteria were developed to allow for infiltration in new sewers. The general philosophy was that, since storm sewers carry innocuous rainwater, the installation of tight sewers was of minor importance. Likewise, since combined sewers and interceptors were and are designed to receive certain amounts of stormwater, there was general belief that liberal allowances should be made for infiltration. Sanitary sewers by nature restrict the carriage of stormwater, but many cities allow areaway drains, foundation drains, or even roof leaders to be connected to sanitary sewers. Therefore, the sanitary sewers are designed for varying amounts of water other than sanitary wastewater. In all instances examined, the design criteria for sanitary sewers include allowances for infiltration. There is an increasing awareness that these design allowances can be reduced because of improved joints, more rigid inspection, and improved methods for correcting leaks and breaks. However, these changes are slow and far from universal. Meanwhile the added tax burden is enormous.

To continue the 50-year-old philosophy that infiltration is a necessary evil to be tolerated at the same old rate is poor engineering judgment and administrative procedure. The effects of excessive infiltration are most prevalent in sanitary sewer systems and interceptors. Many cities report the yearly amount of infiltration to equal or exceed the amount of sanitary wastewater. This can only mean the installation of larger sewers and severe limitations on existing sewers as growth occurs. It means providing relief in the form of new sewers or tolerating overflow to the stream with resulting deterioration of stream quality. As for treatment, it means the added cost of a larger plant to accommodate the increased hydraulic load or bypassing the excess flow to the watercourse, thus negating the purpose of the treatment plant.

To illustrate the general problem, there is included here a study of infiltration from all sources to the sanitary sewers of one residential area served by so-called "separate" sewers. Infiltration in this instance included groundwater and direct connections from foundation drains, downspouts, area drains, etc. At Mission Township Main Sewer District No. 1, Johnson County, Kans., Weller and Nelson (23) found that over a 4-year period the average wastewater flow in the sanitary sewer system was more than 3 times the average water used. Thus, the major flow originated from sources other than the water supply. It was concluded that during moderate storms the major stormwater entry into the sewers was from house foundation drains which apparently were connected directly to the sewers. Other sources of direct connections and their proportions, based on residences rather than people, included downspouts, 13 percent; flooding through surface entry into basement, 7 percent; areaway or patio drains, 5 percent; and driveway drains, 3 percent. Of these, the driveway drains were considered to be the most important from a hydraulic loading standpoint.

Infiltration is somewhat less important in storm sewers because the treatment plant is not affected. However, it is reasonable to assume that by utilizing all possible improvements in materials, design, and construction it would be possible to reduce the size of new pipe required, or for existing pipe to carry more runoff.

Pumping stations and other appurtenances also are directly affected by the quantity of infiltration in any type sewer.

Existing infiltration allowances vary widely. Interceptor design allowances from only a few sources are reported to average from 500 to 4,000 gpd per acre. Assuming a metropolitan area of 3,000 acres, the infiltration would range from 1.5 to 12 mgd. It also is reported for sanitary sewers that infiltration allowances of 50 gcd are made. For a city of 1 million sewered population this would amount to 50 mgd *in the sanitary system.* Hydraulically, this can mean collection and treatment facilities for a city of approximately 500,000. The cost burden is obvious.

Corrective measures involve both new and existing sewers. New sewers involve the use of more rigid specifications, including new jointing methods, more stringent construction requirements, and improved construction inspection and testing. Also required is a continuing followup to prevent illicit connections, such as roof leaders and yard drains, where excluded by design. For existing sewers with breaks or bad joints it no longer is necessary to excavate and repair or replace faulty sections or joints. Television inspection and inplace sealing methods have become available in recent years. Continued improvements of these and other methods are expected.

The effects and economic burden throughout the country imposed by extensive infiltration appear to warrant a major effort toward improvement of existing situations and the encouragement of new installations which will exclude as much infiltration as possible.

Remedial Methods

The 50-plus engineering and special reports examined are not necessarily representative of the national problem, but they formed the only available sample. Since they represent a sizable portion of the population affected by combined sewer overflows and stormwater discharges, the variety of solutions considered or initiated by these communities is significant in assessing the overall problem. A tabulation was made (table XIV) from these reports showing various remedial measures considered, recommended, and executed to solve the problem of control and treatment of combined sewer overflows and stormwater sewer discharges. Some explanation is necessary in order to interpret the data to the best advantage. Because of the differing environmental influences and other factors peculiar to each community, and because of the comprehensive nature of engineering investigations, many solutions are considered and in some instances several simultaneous courses of action are recommended. For these reasons there are multiple entries in the table.

For convenience in evaluating this information, the courses of action are grouped in two general headings—primary and alternate. The primary course of action, sewer separation, is subdivided into separate storm sewers, separate sanitary sewers, separate roof drains, separate yard and areaway drains, separate air-conditioner flows, separate foundation drains, separate catch basin drains, and separate water cooling systems.

Primary Methods

The first two of these "Primary" subdivisions appear in the forms shown because some communities considered the installation of new separate storm sewers with the use of existing combined sewers for sanitary purposes, while others considered the construction of new sanitary sewers with the use of existing combined sewers for stormwater.

Complete separation requires all the courses of action indicated. It is obvious from the data that not only has complete separation not become a reality but the frequency of its consideration and recommendation is low. The financial consideration of making the required changes in existing sewered communities is enormous. Therefore, the tendency has been to recommend the course of action which will fit most practically the community's economic capability. Most often this has resulted in se-

Table XIV.—Remedial Measures for the Control and Treatment of Combined Sewer Overflows and Stormwater Sewer Discharges as Obtained From Various Reports Discussing More Than 50 Communities in the United States.

Remedial measure	Action		
	Considered	Recommended	Executed
(a) Primary			
Sewer separation:			
Separate storm sewers	45	36	9
Separate sanitary sewers	35	29	7
Separate roof drains	26	21	3
Separate yard and areaway drains	10	7	1
Separate air conditioner flows	11	6	1
Separate foundation drains	13	9	1
Separate catch basin inlets	10	7	1
Separate water cooling systems	9	5	0
(b) Alternate			
Treatment:			
New treatment works	4	4	2
Expand, enlarge existing plants	4	2	1
Holding tanks*	9	4	2
Lagoons, ponds, lakes*	9	3	1
Storage:			
Additional sewer capacity	27	22	5
Bleed to treatment or streams**	3	3	1
Guttering	4	3	1
Inlet retention	1	1	1
Street and roadway retention	5	4	2
Miscellaneous:			
Improved zoning and land control use	4	3	3
Control of infiltration	9	7	......
Regulation, diversion, and monitoring	2	2	......

*Also classed as storage.
**Considered with operation of holding methods.

lecting the degree of partial separation beyond separate sewers which can be done with the greatest ease and least cost and yet provide maximum benefits.

The table indicates that, in addition to separate sewers, the change most commonly recommended is to connect roof drains with storm sewers. This can be done by direct connection to the sewers or by connection of the roof drains to catch basins. The data further show that, while engineering studies have led to recommendations in several locations to provide all the steps for complete separation, the communities usually have chosen not to execute the complete list. Undoubtedly, the major factor in these compromises is the heavy financial burden.

Further analysis of the data reveals that only one of the communities surveyed is implementing recommendations for a complete separation program. This is being accomplished under a planned 60-year program and is not in reality providing total separation because of incomplete cooperation on the part of individual property owners and because of other technical factors.

It is also clearly shown that many communities did not consider total separation, but for those which did, some two-thirds to three-fourths of the engineers recommended total separation. That a higher proportion of the communities did not consider total separation is understandable since many of the studies were authorized specifically for such purposes as the alleviation of local flooding or treatment needs.

Alternate Methods

Alternate methods considered are grouped under the three headings of (a) treatment, (b) storage, and (c) miscellaneous. However, the methods are here discussed in the order of their frequency of consideration.

1. *Additional Sewer Capacity*

Of the alternate methods considered, by far the most frequent recommendation was for additional sewer capacity. This is logical since the individual studies revealed that the present systems were inadequate to handle the combined and stormwater flows. Reasons for the inadequacy include both increased number of connections and increased concentration of population. Addition of industrial wastes, although largely undefined as to specific quality, is a factor. Increased infiltration is a further contributor, as is an increase in runoff due to a larger area of paved or other impervious surface.

2. *Control of Infiltration*

The next most frequent method and positive recommendation was control of infiltration.

This has been discussed in detail earlier in this report.

3. *New or Enlarged Treatment Plants*

Treatment methods also were considered by a number of communities. Considerations were about equally divided between new or expanded wastewater treatment plants, and holding tanks and lagoons or natural bodies of water. None of these methods is a new solution, but there is considerable diversity of opinion as to the relative merits of the holding-type treatment and much work is needed to clarify the various factors.

One of the alternates is the construction of additional treatment facilities or the enlargement of existing treatment plants to accommodate the added load imposed by overflows and/or stormwater. In some respects this is not an alternate solution, but when considered in the light that the plant would be provided or enlarged to prevent the discharge of excessive high-strength overflows, then it is an alternate. Separate treatment of stormwater alone could become necessary. In reality, it is not known whether this will become necessary or, for that matter, feasible, because of the many variables. Valid comparisons with other methods of solution must await more factual information.

There is some overlap in the classification of the alternate methods. For instance, holding tanks, lagoons, ponds, and lakes are storage devices as well as treatment methods.

4. *Holding Tanks*

There has been much interest in the use of holding tanks because they permit a delay of high peak discharges sufficiently long to allow a leveling of load to the sewers. When holding tanks are used to contain the flow within the system, that is, to prevent or limit overflow, the problem is transmitted to the treatment plant. This procedure requires that the treatment plant be able to handle the load. If it cannot, then the excess will be bypassed and the result is the same as with no holding tanks, except that grit and other heavy solids can be removed in the holding tank.

Another use of the holding tank is for treatment. The treatment may be removal of solids, or such removal plus chlorination for disinfection of pathogenic organisms. In Boston, for instance, holding tanks are used and the retained flow, after chlorination, is discharged directly into Boston harbor on each outgoing tide.

Holding tanks are not new. Columbus, Ohio, as an example, has had them for 30 years. New York City recently announced plans for an extensive system of holding tanks which will receive overflows from combined sewers, provide hypochlorination to the influents through three vertical pipes in each inlet sewer, and return the effluent to the system for transfer to existing wastewater treatment plants (24). There will be four plants designed to hold a total of 37.5 million gallons for this purpose. The announced aim is to eliminate beach pollution.

5. *Lagoons, Ponds, Lakes*

Lagoons, ponds, and lakes, also suggested, are similar to holding tanks. These bodies of water will hold and level the flow, and they also will act as stabilization ponds if the flow is held for an appreciable time. The use of these may have been suggested by a natural depression, such as a quarry, near an area needing surcharge capacity, as was the case at Buffalo, N.Y. In other instances, the depression may be designed and built for the purpose.

Lake Temescal in Oakland, Calif., is an artificial lake which is used as a balancing reservoir. Originally it was a water supply reservoir but was abandoned for this use as the watershed was developed. Concurrent with use as a stormwater holding device has been its use for recreational purposes. Lakes in the Seattle, Wash., area have been considered for the same purpose. On the other hand, Tacoma, Wash., built a lagoon to control stormwater damage in nearby areas.

Lagoons also provide possibilities for multiple water use. They have been considered in the Chicago area where industrial water sometimes is short. The stored water would receive treatment prior to use by the industry.

One community considered the use of surge tanks to store temporarily in storms the water discharged from large water users.

6. *Guttering, Inlet Retention, and Street and Roadway Retention*

A method judged to be of somewhat lesser potential is a program of storage through the use of guttering, catch basin, inlet retention, and roadway detention. With proper design there can be some delay in the runoff reaching the sewer system which will reduce the overflows at diversion points in the system.

7. *Disinfection*

Separate chlorination of stormwater and/or combined overflow in continuous contact chambers is another alternate method. Camp (3) reported results of tests to determine chlorine dosage requirements and discussed the applications of the method. He indicated that in many instances it should be possible to use unlined earthen chambers as contact tanks. Contact surface areas required were roughly from 1 acre for a tributary area of 1 square mile to 5 acres for a tributary area of 10 square miles. He found that a chlorine dose of not more than 10 times the average required for dry-weather flow would be adequate.

8. *Improved Zoning and Land Use Control*

Improved zoning and control of land use are factors which must be considered in providing alternate solutions. Constant changes in zoning with resulting change in land use and surface characteristics as well as population densities impose conditions for which existing sewer systems were not designed. These continuing changes suggest that advance planning on an areawide basis would be of significant help in making it possible to use a collection system to best advantage.

9. *Regulation, Diversion, and Monitoring*

Regulation, diversion, and monitoring comprise still another method of control. Minneapolis, Minn., is considering a plan of automatic control and regulation of its combined system to reduce the frequency of overflows. This is in conjunction with the city's long-range separation program and in concept utilizes the sewer capacity for storage. Also, Cincinnati, Ohio, is considering a monitoring program to evaluate and hopefully arrive at a solution to its problem of excessive overflows.

Studies by Others

During their work on metropolitan Seattle's sewerage and drainage survey, Brown and Caldwell (25), in 1957, compiled information from 16 other cities in the United States and Canada regarding separation of combined systems. While there have been changes since this survey, the results in general remain valid.

Nine of the 16 cities studied by Brown and Caldwell are included in the current study. These include Baltimore, Md.; Boston, Mass.; Buffalo, N.Y.; Chicago, Ill.; Detroit, Mich.; St. Louis, Mo.; Minneapolis, Minn.; New York, N.Y.; Oakland, Calif.; Portland, Oreg.; Spokane, Wash.; St. Paul, Minn.; Toledo, Ohio; Vancouver, British Columbia; Washington, D.C.; and Winnipeg, Manitoba.

Three cities (Baltimore, Oakland, and Toledo) have sewers and storm drains which are principally separate. Five (Chicago, Detroit, St. Louis, Spokane, and Winnipeg) have mostly combined sewers; and 8 (Boston, Buffalo, Minneapolis, New York, Portland, St. Paul, Vancouver, and Washington) have combinations of separate and combined systems.

Roof drainage is allowed to discharge to the ground surface in half of these cities. In several, the roof drainage goes into the street gutter by way of a surface drain or leader from the house.

Foundation drainage is discharged to the sanitary sewers in seven of the cities (Buffalo, St. Louis, Oakland, Spokane, Toledo, Washington, and Winnipeg) except in a few cases where storm drains are deep enough to receive it. In Baltimore and Vancouver, storm sewers, where provided, are designed to receive foundation drainage. Seven of 10 cities reported that present residential drainage practices must be modified to conform to separation programs underway. Boston, Buffalo, and St. Paul indicated that cost and other obstacles made it infeasible to require alteration of connections to effect complete separation.

The cities of Buffalo, St. Louis, Minneapolis, Spokane, Toledo, and Vancouver allow basement drains into the sanitary system while Washington does not.

Five cities (Baltimore, Boston, Buffalo, Minneapolis, and Washington) are currently financing separation with general funds or have done so in the past; however, most of their work applies to systems nearly complete or is of comparatively minor nature. Washington is a notable exception where a major project is being financed by general funds.

Most of the cities report financing as the major problem in a separation program. Five cities (Buffalo, Chicago, Detroit, St. Louis, and New York) either indicated or implied that no separation was proposed.

The study revealed a trend toward separation as water quality standards improve, but that separation depends on local factors and that each case must be worked out in the light of controlling conditions.

In general, it is believed that the final answer will depend on: (a) the capacity of existing sewers, (b) the frequency and intensity of rainfall, (c) the importance and uses of the water into which is discharged the overflow of diluted sewage and stormwater, and (d) the cost of construction and maintenance.

Costs

Complete Separation

Estimated costs for complete separation as reported by 16 cities are given in table XV. Toronto, Ontario, is included in the table as a matter of interest, but is not included in the computations. The 15 U.S. cities represent sewered populations of approximately 21 million and indicate a total cost of $9.4 billion.

Table XV.—Estimated Costs for Complete Separation of Stormwater and Sanitary Sewers

City	Total project cost	Cost/acre	Cost/capita
Chicago, Ill.	$2,300,000,000	$17,000	$482
Cleveland, Ohio	470,000,000–700,000,000	12,000–18,000	360–535
Concord, N.H.	8,000,000	....	280
Detroit, Mich.	1,315,000,000	....	360
Haverhill, Mass.	30,000,000	10,500	650
Kansas City, Kans.	20,000,000	[1] 7,745	187
Lawrence, Kans.	30,000,000	13,500	915
Lowell, Mass.	70,000,000	12,000	780
Milwaukee, Wis.	425,000,000	8,250	440
New Haven, Conn.	10,000,000	[1] 16,363	560
New York, N.Y.	4,000,000,000	25,000–30,000	492
Portland, Oreg.	100,000,000–250,000,000	3,100–7,750	260–652
Seattle, Wash.	145,000,000	3,890	260
Spokane, Wash.	50,000,000	1,800	415
Toronto, Ontario	285,000,000	17,000	....
Washington, D.C.	214,000,000	18,000	250
Total	[2] 9,662,000,000	[2] 12,427	[2] 468

[1] Based on actual project cost.
[2] Using the average costs for those cities reporting ranges. U.S. only.

Eight are large cities with serious problems and therefore may provide an unbalanced sampling for projection purposes. Indicated costs per acre of city area vary from $1,800 to $30,000 and average $11,800. Computed on a per capita basis, the ranges are narrower, from $187 to $915, with an average of $465.

Even though there is considerable reason to doubt the validity of direct projection of these costs to obtain a total estimate for the United States, they are offered here as a base from which other estimates can be drawn.

Assuming that this is a representative sample and using the total number of people (59 million) served by combined sewer systems and by combinations of combined and separate systems as shown in table I, the total United States cost for complete separation would be $27.4 billion. This assumes that all communities fall within the limits of the sample, which is believed to be too small to be reliable.

It might at first be predicted that the cost per capita is less in large cities than in small communities; however, this is not demonstrated in the data. The eight large cities represent about 20.5 million people and the average cost per capita is $400, while the nine smaller cities total about 0.6 million and the average cost is $540 per capita. Therefore, the total cost could well be more than $27.4 billion. Further, these cost figures do not represent 1964 dollars. Most are from preliminary estimates and some are several years old.

These rather crude manipulations of data indicate that total separation costs could amount to $25–$30 billion, or even more.

Partial Separation

Costs of partial separation are more difficult to bracket because of the varying degrees of separation proposed. Therefore, less reliance is placed on the ability to place the cost estimates in a common frame of reference.

Partial separation costs vary with the extent of separation of roof drains, areaway drains, foundation drains, air conditioning and other cooling water, and yard drains. One city will permit certain of these waste sources in the sanitary sewer while others will not (25). Some will permit combinations such as allowing owners to pump foundation drains to sanitary sewers.

The project may be separation of sewers only, or it may be separation of sewers plus separation of one or more of the additional sources of stormwater in sanitary sewers.

With these conditions as background, the available partial separation costs are shown in table XVI.

Information was available from 18 communities totalling 2.1 million people. Estimated costs for the various projects covered total $244 million. Cost per acre was available from only seven cities, but from those the variation was great—from $640 to $7,800 and averaging $3,045. The cost per capita ranged from $43 to $500 with an average of $176.

Table XVI.—Estimated Costs for Partial Separation of Stormwater and Sanitary Sewers

City	Total project cost	Cost/acre	Cost/capita
Des Moines, Iowa	$25,000,000	$7,800	$170
Elmhurst, Ill	8,770,000	....	237
Eugene, Oreg	3,410,000	3,100	76
Findlay, Ohio	15,108,000	....	500
Granite City, Ill	13,200,000	4,900	330
Hannibal, Mo	613,000	....	43
Kendallville, Ind	969,000	....	143
Lafayette, Ind	5,024,000	....	120
La Porte, Ind	9,187,000	....	437
Lathrup Village, Mich	961,500	....	302
Louisville, Ky	30,538,000	....	73
Michigan City, Ind	3,500,000	....	95
Minneapolis, Minn	30,000,000	3,040	69
Mishawaka, Ind	4,392,000	972	129
Napa, Colo	1,549,000	640	52
Sedalia, Mo	4,470,000	....	213
Seattle, Wash	69,000,000	1,860	124
Tacoma, Wash	7,960,000	....	53
Total	233,651,500	[1] 3,187	[1] 176

[1] Average.

Using the same assumptions as for total separation, the nationwide United States cost for partial separation would be $10.4 billion. Although this total is believed to be far less reliable than the estimate for total separation, it shows the order of magnitude of the problem's financial aspects.

Unit Costs for Individual Separation Items

Little information was available for single-item costs in a separation project.

Seattle and Tacoma provided unit cost estimates as follows:

House sewer reconnections	$40.00
Catch basin reconnections	80.00
Manhole connections	100.00
New house sewers	300.00

Washington, D.C., estimated the following unit costs for changes of plumbing and house connections:

Single-family house, unfinished basement	$1,200
Single-family house, no basement	2,000
Small apartment with basement	1,750
Larger apartment, at least	5,000
Shop with storage basement	2,000
Shops, no basement	4,500
Shops, store, office building, with basement	5,000

All unit-cost information is believed to be too limited to make any generalization for other areas.

Alternate Methods

1. *Holding Tanks*

More data were available for holding tanks than for other alternate methods. Available costs appear in table XVII.

Table XVII.—Available Costs for Holding Tanks for Temporary Impoundment of Combined and/or Stormwater Overflows

City	Total project cost	Cost per acre	Cost per capita
Clinton, Iowa	$2,655,000	$1,400	$88
Haverhill, Mass	25,000,000	8,800	545
Lawrence, Mass	21,000,000	9,500	300
Lowell, Mass	53,000,000	9,150	590
Mission Township Main Sewer District No. 1, Kans.	4,000,000	1,000	67
New York, N.Y.			
Jamaica Bay	65,000,000	5,150	(1)
Eastchester Bay	35,000,000	....	(1)
Upper East River	81,000,000	2,130	(1)
		[2] 5,304	[2] 318

[1] Unknown population served.
[2] Average.

There are wide variations in the extent and characteristics of holding tank projects, which account for the range in unit costs. The cost information may be useful to establish ranges, but again the many local factors make it difficult to generalize from averages. The New York City project, for instance (24), has been under study for some time but actual construction costs are not firmly established. It will eventually cover three drainage areas in and around New York City and will be done in three phases over a period of several years. The available estimates for these projects total $181 million, while the estimate for total separation was $4 billion. However, the holding tank project covers only a part of the area included in the total separation estimate. Evaluation of the effectiveness of this holding tank project of necessity will not be possible for some time.

There is little operational information available from any source to evaluate the holding tank method. Columbus, Ohio's holding tanks, built in 1934, are reported to be generally successful. However, cleaning operations are reported to result in load problems at the wastewater-treatment plant which receives the settled material. Odor complaints also have been received during tank cleaning operations.

No uniformity in design criteria is apparent. Some tanks may be designed for short-time balancing to control surcharging while others are designed for partial treatment by settling and chlorination of the overflow. Relationships between tributary area and holding tank capacities are necessary but these relationships are subject to considerable modification by local conditions.

2. *Chlorine Contact Tanks*

Cost information for three cities with chlorine contact tanks was located. These costs appear in table XVIII. Unit costs were quite uniform at about $4,200/acre. Per capita costs of two were in close agreement, in the order of $250, while the third was about $100 less. All three being in the same geographical area imposes limits on the general usefulness of this information elsewhere.

Since chlorine contact tanks have little effect on the removal of solids or BOD their primary purpose of partial disinfection is limited in ultimate usefulness as compared to complete separation and treatment and some of the other methods. However, the control of coliform organisms and viruses as protection for water supply, recreational, shellfish propagation, crop irrigation, or other water uses must be assigned high priority. The method needs extensive evaluation in several locations to establish its long-range merits.

Although the cost of chlorine contact tanks is far less than separation and holding tanks, the cost of chlorine in the operation must be included in the full cost. For the three cities from which information was available, this cost amounted to about 50 cents/person/year.

Table XVIII.—Costs of Chlorine Contact Tanks for Partial Disinfection of Combined and/or Stormwater Overflows

City	Total project cost	Cost per acre	Cost per capita
Haverhill, Mass	[1] $11,500,000	$4,050	$250
Lawrence, Mass	[2] 9,800,000	4,400	140
Lowell, Mass	[3] 23,700,000	4,060	264

[1] Annual chlorine cost, $30,000.
[2] Annual chlorine cost, $24,000.
[3] Annual chlorine cost, $56,000.

3. *Lagoons, Ponds, and Lakes*

Although lagoons, ponds, and lakes have been used as control methods, cost data were meager. In some reported instances, existing ponds, lakes, or quarries were used and this made it difficult to assign costs to the projects. In other instances, cost breakdowns were not clear because the storage facilities were included as a part of multiple use projects involving other installations.

With these limitations, costs were available for only three installations as shown in table XIX.

Table XIX.—Costs of Lagoons Used for Controlling Stormwater Flow

City	Total project cost	Cost per acre	Cost per capita
Exeter, N.H.	$320,000	$640	$80
Richards Gebaur Air Force Base, Mo.	280,000	700	......
Takoma, Wash	115,000	[1] 39	[1] 19

[1] Estimated from incomplete data.

These costs have no degree of reliability for comparative analyses except that unit costs appear to be substantially below other alternate methods discussed.

4. *Other Storage Methods*

Specific costs were unavailable on the other storage methods considered.

Those cities which have provided additional sewer capacity have not made clear the costs for this purpose because other sewers are involved in the projects. Special analyses of these projects would be necessary to break out the costs attributable solely to extra storage capacity.

Similar analysis problems were apparent in considering guttering, inlet retention, and street and roadway retention.

5. *Other Treatment Methods*

Where new and/or expanded treatment works were considered, costs again were included with other treatment benefits and were not amenable to separate accounting.

6. *Miscellaneous Methods*

Although three communities have instituted improvements in zoning and land use control, specific costs or values of benefits were not available. Only two cities are studying regulation, diversion, and monitoring to evaluate their usefulness and costs in relation to stormwater overflows. Their studies were in the preliminary stages and hence the information was quite limited. However, each city indicated expenditures of about $1 million for installation of monitoring and regulation equipment.

Discussion

Only a sampling of the overall problem of stormwater and combined sewer overflows was possible in this preliminary investigation with its limited sources of information. Nevertheless this sampling should sufficiently indicate the character and magnitude of the problems and hopefully it will provide guidelines toward solutions.

Stormwater and overflows from combined sewers constitute problems which increase with urbanization and the attendant rise in water usage. The problems vary from basement and street flooding to gross pollution of water courses which often must be used for high quality purposes such as drinking water supplies. Local studies by various cities over a period of many years have recognized the problems, and some are proceeding under enormous financial burdens toward corrective measures.

There are many indications of local study and partial action on the problem but there has been no nationwide assessment. Local experiences make it clear that many factors peculiar to each area make it difficult to generalize concerning corrective measures. Weather conditions, land contours, and land uses, differ from place to place. Streams vary in size, character, and in the use that is made of them. Types of sewers, concentration of population, incidence of industry, and other factors have their influence.

This report attempts to define the problems and it explores possible solutions along with the all-important costs.

Reliable data are difficult to accumulate because most sources were but preliminary studies, and many of these explored only a single phase of the problems arising from stormwater and combined overflows. This made it necessary to selectively extract data which in many cases were mixed with other project studies. Despite the limitations inherent in this method of approach, it is felt that the study here documented reveals many significant facts.

Problems posed by combined sewer systems are of major significance. Fifty-nine million people live in 1,940 U.S. communities whose sewer systems are wholly or partially of the combined type which must carry both municipal sewage and excess stormwaters. If a majority of these communities share the all-too-common problem of sewer overflow and inadequate treatment plant capacity in periods of heavy rainfall, there is cause for real concern.

The study reveals that many communities experience overflows from combined sewers in significant quantity even in dry weather. In fact, some systems are designed to accommodate this situation. This means that unknown quantities of relatively high pollutional strength wastewater are being discharged untreated to receiving streams. Few cities systematically measure the quantity or quality of these discharges.

In terms of quantity, the study reveals that an average of 3 to 5 percent of all raw wastewater is annually discharged by overflow from combined sewers to watercourses. Based on the 59 million population affected by combined sewers or partially combined sewer systems and figuring the minimum 3 percent overflow, nearly 65 billion gallons of raw sewage per year enter the Nation's watercourses during storms. This amount does not include the stormwater which was not estimated as to total quantity. However, the combined overflows would contribute to the watercourses annually about 100 million pounds of BOD attributed to domestic wastewater only. Most of this could be prevented if the overflow conditions did not exist.

The degree of bacterial contamination contributed to the watercourses by overflows was shown to be far beyond that which will allow the streams to meet accepted standards. Storms which occur in the summer on the average of once every few days overtax the receiving waters and render them unsuitable for recreational and other uses.

It was also confirmed that stormwater alone carries significant organic, inorganic, and bacterial contamination to streams. The greatest load occurs at the beginning of the storm. Particularly disturbing is the widespread confirmation that during storms up to 95 percent of the sanitary waste is discharged to the stream by overflow.

Based on quantity and quality analyses of stormwater and combined overflows, the problem is of major significance. However, there is much to be learned in order to define the entire problem more clearly.

Evidence of various damages caused by stormwater and overflows was common. The most frequent is basement flooding with its obvious health implications. Included among other damages were nuisances, decreased property values, impaired recreational use of waters, and increased treatment cost. It was not possible to relate dollar values to these damages but the amounts implicated are enormous. Studies are needed to establish damage-cost relationships. The full range of water uses is affected.

Throughout the study it was repeatedly demonstrated that investigations of the many-faceted stormwater and combined sewer overflow problem are meager, scattered and generally incomplete. Such fundamental factors as the effect of such discharges on stream quality are relatively undocumented. Without doubt, deleterious effects are imposed on streams but the precise degrees are largely unknown or unavailable. Obviously, to place the problem in proper perspective, more work is needed in this area.

Another of the persistent problems is the gross hydraulic load imposed on the sewer system and treatment facilities by infiltration. When cities of 1 million population deliberately design their sewer system to accommodate 50 gpd/capita, or 50 mgd of infiltration, the time is overdue to investigate means of eliminating or materially reducing such practice. Improvements in jointing materials, in detection of sewer leaks, and repair methods should be investigated thoroughly.

Adding to the overall problem is the omission in most of the source information of any consideration of industrial contributions to the overflows. Industrial wastes intensify the problem and there are strong indications from some sources that the industrial waste contribution is substantial.

The second phase of the study examines methods and costs for solving the problem.

Complete separation of storm and sanitary sewers and treatment of all waste, both sanitary and storm would provide ultimate protection to watercourses. Short of this are various compromise measures with varying degrees of benefits.

A few separation projects are underway, mostly in larger cities, and all under long-range plans. Invariably, even though the needs are clear, the projects are delayed or reduced because of the enormous financial burdens. Rough estimates of complete separation costs for the United States are in the 25 to 30-billion-dollar range, and possibly more.

Not considered in assembling the cost information is the monetary loss which occurs as the result of physical inconveniences during the construction period in a separation project. Extensive excavation is necessary in streets and other areas and progress usually is slow. Individuals, businesses, industrial establishments, and, in fact, entire communities are subjected to temporary economic loss because of inaccessibility. Here again it was not possible to assign dollar values, but the amount would no doubt be substantial.

The complex and long-range nature of the problem makes it a fundamental part of metropolitan regional planning. In this regard, planners need to be supplied more and better information.

Partial separation, in the various degrees considered and executed, can provide substantial relief. Several cities have initiated this type of program, perhaps in the hope that full separation can be provided later. As would be expected, costs are somewhat less than for complete separation but still are impressive. The degree of protection afforded to receiving waters is unknown in detail and requires further evaluation.

Alternate methods have been considered and used, though most have received only cursory evaluation. New York has launched the most extensive program utilizing alternate methods. A series of combined overflow holding tanks is being installed with chorination of the effluent prior to its return to the sanitary treatment system. This method was selected because of its smaller cost in comparison with total separation. Evaluation of its effectiveness will not be known for some time.

Other methods in use include lagoons, lakes, or abandoned quarries; and chlorine contact chambers. Several other methods have been considered and it is expected that still others having more effectiveness, perhaps at less cost, will be developed. Intensive study of separation methods and alternate solutions is strongly recommended. There is real concern that increasing urbanization will result in combined sewer and stormwater overflows discharging organic loads to the Nation's streams which will increase at a rate greater than existing or planned corrective efforts can handle.

Conclusions

The preliminary study of the nature and characteristics of stormwater and combined sewer overflows, their effects on watercourses, and possible solutions to problems created revealed the following:

1. Approximately 59 million people in more than 1,900 communities are served by combined sewers and combinations of combined and separate sewer systems.

2. Existing sewer systems are inadequate to handle sanitary wastewater and stormwater without creating excessive overloads at treatment plants and throughout the sewer systems, and as a result these overloads are discharged to the available water courses.

3. Stormwater and combined sewer overflows are responsible for major amounts of polluting material in the Nation's receiving waters and the tendency with growing urbanization is for these amounts to increase.

4. Both combined overflows and stormwater contribute significant amounts of pollutional materials to watercourses.

5. These discharges affect all known water uses adversely in the receiving water courses.

6. Significant economic loss results from the damages caused by these discharges although precise levels of these damages remain to be determined.

7. Damages occur more frequently during the summer storm season but many systems are so overloaded that overflow occurs during dry weather throughout the year.

8. Infiltration is a major problem contributing to hydraulic overloading of sanitary, combined, and storm sewers.

9. Complete separation of stormwater from sanitary sewers and treatment of all waste is the ultimate control measure to provide maximum protection to receiving waters.

10. Other solutions which have been considered, separately or in combination, include: (a) partial separation of roof, yard, areaway, foundation, and catch basin drains from sanitary and combined sewers; (b) expanded or new treatment facilities; (c) holding tanks, with or without chlorination; (d) disinfection; (e) storage using lagoons, lakes, quarries, and other depressions; (f) storage using guttering, streets and roadways, and inlets; (g) additional sewer capacity; (h) regulation and control of flow through the sewer system; and (i) improved planning and zoning.

11. Evaluation of the effectiveness of all methods except complete separation is unavailable because of the lack of installations to study.

12. Total costs for complete separation based on scattered information are estimated to be in the $20 to $30-billion range.

13. Costs for partial separation are estimated to be a substantial fraction of those for complete separations and costs for alternate methods are estimated to be in the multibillion-dollar bracket.

Recommendations

Based on the study reported herein, recommendations for action are as follows:

1. Comprehensive studies should be initiated to expand on the preliminary study and explore in depth its objectives. These studies should be sufficiently detailed to provide an understanding, on a national basis, of the present limits, reliable predictions for the future, methods of solution, and costs. In the examination and evaluation of methods for correction, projects must be sufficiently large to be assured of practical results. In the economic analysis full recognition should be given to evaluation of present and potential losses or deleterious effects in relation to protection of the nation's waters for public use.

2. Extensive followup studies should be carried on to provide full evaluation of the corrective methods.

3. Demonstration projects for the development of new or improved methods for controlling the discharge of sewage and stormwater from combined sewer systems would provide an effective mechanism for the conduct of these studies and the acquisition of actual design, construction, and performance data. They would have the added advantage of representing an attack on the problem as well as providing information for future action.

4. Final recommendations for solution of the problem on a massive basis must await results of the studies recommended herein.

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Appendix

Engineering Reports, Completed Questionnaires, and Special Reports Referred to in Study of Combined Sewer Overflows and Stormwater Discharges

Engineering Reports and Completed Questionnaires

1. "Sewage Treatment Works and Intercepting Trunk Sewers for the City of Amsterdam, N.Y." William S. Lozier Co., Rochester, N.Y. (Aug. 1947).

2. "Preliminary Report on Sanitary Sewage Collection and Treatment for Ashland, Kentucky." J. Stephen Watkins, Lexington, Ky. and Howard K. Bell, Lexington, Ky. (Dec. 15, 1957).

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23. "City of LaPorte, Indiana—Sewerage and Drainage." Charles W. Cole & Son, South Bend, Ind. (1962).

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U.S. GOVERNMENT PRINTING OFFICE : 1964 O—744-996

PUBLIC HEALTH SERVICE PUBLICATION NO. 1246

1964